THE ANORTHOSITES OF BENGAL

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THE ANORTHOSITES OF BENGAL

ABSTRACT

The anorthosite rocks of Bengal occur as an elongated sheetlike mass within the Archaean rocks, along the northern part of the district of Bankura, and extend into the adjoining district of Manbhum. There are associated granite and norite dikes and contemporaneous veins. The structural relation, microscopic characters and chemical composition of all the three types and other varieties are fully indicated and discussed in relation to their bearing on the mode of origin of the anorthosite rocks in the light of researches done in recent times in America. Bowen's ideas as modified by Balk seem to offer a satisfactory explanation of most of the observed phenomena.

I. INTRODUCTION

Ever since Bowen wrote his classical paper on the "Problem of the Anorthosites" (Bowen, 1917), there has been a great deal of controversy on the question of their origin and there is even now a considerable difference of opinion among petrologists on some of the major problems. It was thought that a careful record of field observation and laboratory work on a hithertofore little-known body of anorthosite might throw some light on the problem. A detailed study of the anorthosites of Bengal was therefore undertaken some years ago at the suggestion of the late Prof. Dasgupta. The purpose of the present paper is to record the observed facts and to consider the applicability of the several theories proposed by different petrologists to the interesting problem of the origin of anorthositic rocks.

II. PREVIOUS WORKERS

The first systematic geological account of this area was given by Oldham in 1859 before the name "Anorthosite" came into use in geological literature.*† Oldham recognised the feldspathic nature of the rocks in the eastern part of the area under description and the greater

* Mem. Geo. Surv. of India, Vol. I, p. 255.

† The name Anorthosite was first proposed by Sterry Hunt in 1863 in his Geology of Canada.

liabikty to weathering of the more feldspathic varieties. The massive anorthosites of Ramchunderpur were described as a curious granitite "composed of quartz and felspar with imbedded crystals of a second felspar of a leaden grey colour." The occurrence of trap dikes and granite veins in these rocks were also noted by him.

The next account of the geology of this area is found in Ball's Geology of Manbhum and Singhbhum (Ball, 1881). The rocks described by him as 'rusty-looking quartzite' and 'felspar porphyry' are probably anorthosites. According to Ball these rocks 'are traceable for a distance of about 7 miles, after which they die out' and are followed by traplike hornblendic rocks. The latter seemed either to be greenstones and diorites or hornblendic schists.

Sir Thomas Holland first identified these anorthosites and norites near the south border of the Raniganj coalfield (Holland, 1900). I take the liberty of quoting in full the important observations made by Sir Thomas Holland :—

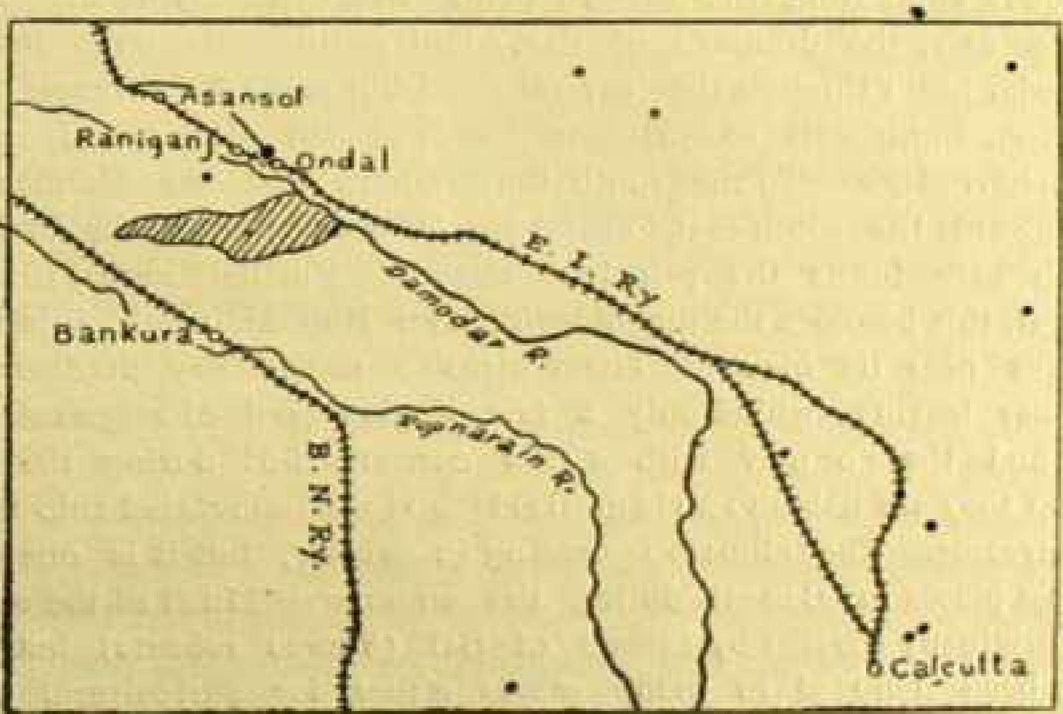
> "The Norites are fine-grained and granulitic, sometimes foliated and sometimes showing an occasional garnet. The labradorite rocks are very variable in the size of their crystals, the ferromagnesian constituents which occur in comparatively small quantities, include an occasional olivine with well defined reaction rims."

The present author undertook a detailed study of these rocks in 1928 and published a short preliminary note on them in 1929 (Chatterjee, 1929). Since then he has been engaged in a systematic mapping of the different scattered outcrops. During the last few years there has been a good deal of intensive study of similar rocks, especially in America, and the writer has taken every opportunity to check all ideas and views of the petrologists engaged in these studies against his own personal observations in the field and in the laboratory.

III. Area and Boundaries

The prevailing idea was that these anorthosite rocks are found only locally near Raniganj, but an attempt to fix its boundaries revealed its greater extension. The rocks were traced for some 18

miles towards the west, and dikes of anorthosite were found even at a distance of 20 miles from Holland's original locality. The main outcrop is comparatively narrow, the width being only five to six miles. It extends from the western bank of the Damodar river in the east, to the neighbourhood of the B. N. railway line to Adra from Kharagpur. The greater part of this narrow zone lies in the district of Bankura in the province of Bengal, but the western extremity lies in the district of Manbhum in the province of Bihar. The entire region lies between lat. 23° 33′ N and lat. 23° 27′ N and between longitude 87° 15′ E to 86° 47′ E. During the present mapping the writer used the following topographical sheets of the Survey of India, all on the scale of 1″=1 mile: 73 $\frac{M}{2}$, $\frac{M}{3}$ and 73 $\frac{I}{14}$, $\frac{I}{15}$. The following sketch map will give a clear idea of the location of the area:



(Scale 1″=64 miles.)

IV. Physical Features, Drainage, Vegetation, etc.

In physiographical features the region marks the transition from the rolling flat alluvial plains of Bengal to the rugged uplands of the Chota Nagpur plateau. The northern and the western parts of the

region are therefore hilly and the surface there is undulating, while in the south and east it merges into the level plains of deltaic Bengal. Exposures of rocks are few and far between, and the geology of the country is completely hidden by the alluvium in most places. The geologist has to confine his attention mostly to the stream sections, but here and there rough hummocky masses of rocks raise their heads above the general surface of the country. North of the region occupied by the anorthosite, the country rocks such as gneiss, schists and sandstones form prominent hills; and similarly in the south the isolated hill of Susunia made of Cuddapah sandstone forms a prominent feature of the landscape.

The central part of the tract is at a slightly higher elevation in many places and forms the chief water-parting of the country. It runs approximately from west-north-west to east-south-east, and gradually sinks into the eastern plain, near the Damodar. North of this axis, the drainage of the country finds its way into the Damodar basin through the several short but rapid hill streams which run from south-west to north-east, such as the Gaighata Jhor and Chouphari Jhor. To the south the Dangra and the Gandheswari run towards the south-east to meet the Dwarakeswar or the Dhalkisor which here forms the principal stream. Further south in lower Bengal, this becomes the magnificent river Rupnarain which joins the Ganges near its mouth. These streams nearly dry up during the summer, leaving behind only a few shallow pools of stagnant water here and there or flow with a slow current, but during the rainy season they are liable to sudden floods and are converted into torrential streams. The climate is bracing in winter, but it is one of the hottest places in Bengal during the summer. Much of the country was originally covered by forests of Sal (*Shorea robusta*) but these have been denuded in many places either for agricultural or for timber-cutting operations. In the rocky upland areas wherever the Sal forests have been destroyed, the vegetation now consists of small bushes of Palash (*Butea frondosa*). In fact the latter now forms the most characteristic and ubiquitous vegetation of the district. Associated with this are Arjun (*Terminalia arjuna*), Kend or ebony (*Diospyros melanoxylon*) and Bat (*Ficus bengalensis*). There are broad extensive upland tracts whose stony soils support a scanty

vegetation of poor grass. In summer the country presents a dry, desolate aspect with its treeless undulating plains, but with the onset of the rains the whole countryside is covered with a mantle of fresh green verdure. Denudation under tropical conditions has produced the characteristic red soils in all the areas characterised by gneissic rocks, but the soil derived from the anorthosite and white feldspathic gneiss and granite consists of alluvium, rich in calcareous concretions (*ghooting*). These are collected in many places as a raw material for lime. It is said that the soil is frequently replenished with this material, as people have been collecting this year after year.

V. Field Relations

The different types of rocks found in the area studied may be put under two groups, namely, the anorthosites together with rocks syngenetic with them and the country rocks. A third group may be made to include the younger intrusive dikes, which cut all the older formations. The intrusive rocks belonging to the anorthosite series may be classified under the following heads :—

(1) Labradorite rocks—White variety of anorthosite.
(2) Anorthosite—Dark variety.
(3) Anorthosite-gabbros.
(4) Granulitic gabbros.
(5) Granites Granodiorites and Grano-anorthosite.
(6) Pegmatites.

The country rocks consist of Dharwars such as hornblende gneiss, sillimanite-biotite schists and gneisses, and intrusive gneisses such as the Bengal gneiss (Chota Nagpur granite gneiss), pyroxene gneiss and quartzo-feldspathic gneisses. These occupy by far the larger area.

Labradorite rocks.

The distinction of labradorite rocks from the anorthosite put under the second group, is based on certain well-marked macroscopic and microscopic differences between the two groups. The labradorite rocks are made up of almost pure plagioclase with a small quantity of dark minerals. The feldspars are white and are not so much schillerised as those of the second group. Occasionally they occur as phenocrysts. In hand specimens the rocks might easily be mistaken for crystalline

limestone, but the characteristic decomposition into whitish clay at once shows the true nature of the rock. These labradorite rocks (white anorthosites) are more common than the dark-coloured anorthosites and are found throughout the area, particularly along the northern strip, and occupy the entire outcrop in the west. The darker varieties occur in the south and east. They are more resistant to weathering and form large roundish and irregular blocks and hummocky masses. (See plate 1, fig. 1.) The white varieties are more liable to decomposition and give rise to masses of white clay. In the low grounds and streams the exposed surfaces are always kaolinised but on well-drained uplands large irregular blocks of fresh rock are often found. Generally speaking the rocks show a feeble development of banding, but here and there in certain zones, the rocks show well-marked schistosity and effects of powerful shearing stress. It may be noted here that microscopic sections of these schistose and sheared varieties show that the rocks are not really anorthosites but are of more acid type. In fact they may be regarded as granodiorites. Variations are often found in the field. The darker facies is scattered widely over the entire region. Here the feldspathic constituents remain as they are, but the dark colour is due to a greater percentage of the femic constituents. These increase in quantity and often segregate together to form dark, irregular, schlieren in the white rocks. In some places the white rock is intimately penetrated by dark sub-parallel bands and the resulting rock looks like a banded gabbro. Schlieren are quite common in the neighbourhood of these bands and the percentage of the femic constituents in the white rocks also increases near these bands. Besides these dark bands there are often dikes of granulitic gabbros and norites. In some places these form large lenticular masses and being more resistant than the labradorite rock stand out as hillocks. These are quite numerous in the region south of Saltora (lat. 23° 31′, long. 86° 56′).

Dark varieties of Anorthosites.

The passage of the white pure plagioclase anorthosite to the dark-coloured varieties is rather sudden without any marked transition. It must not be understood, however, that there is a marked discontinuity (except in one case where the dark variety has intruded into the white

one), but rather there is a sudden passage in the same outcrop from the white to the dark variety. As has been said before the dark colour of the rocks is due to the schillerisation of the feldspars and pyroxenes and the presence of a greater quantity of the femic minerals. On account of the dull grey colour of the schillerised feldspars, there is a superficial resemblance to the intermediate charnockites. They occur as round masses with a characteristic pitted appearance. This is due to the removal of the femic minerals such as biotite, pyroxene and garnet by weathering from the exposed surfaces. Even the most cursory observation indicates that the rock is variable in its texture and coarseness of grain. Every gradation is found from a uniformly fine-grained variety to a coarsely crystalline variety. But the more general type is a porphyritic rock in which large individuals of dark labradorite occur in a finely granulated mass of the same feldspar. Occasionally these phenocrystic feldspars assume unusually large dimensions. In one case a crystal measured $6\frac{1}{2}'' \times 3\frac{1}{2}''$ and in another $13'' \times 5''$. Closer inspection reveals that the feldspar phenocrysts have more or less a parallel arrangement. This feature has been noted also in the case of the white anorthosite wherever fresh surfaces are found. The prevalent parallelism of the large feldspars is characteristic of the anorthosite body as a whole. This may seem at first sight to be the result of dynamic metamorphism, but as these rocks do not show any schistosity or foliation and as the feldspars also occur irregularly in some of the large boulders, it is more probably a result of flow movement of the feldspar crystals in the semi-solid magma, at the time of its intrusion. Besides the above unfoliated types, foliated types are not uncommon, the foliation being probably a primary feature of the rocks, due to the same cause. The general direction of this foliation is approximately east to west and is parallel to the length of the phenocrysts.

Of particular interest is the fact that the dark anorthosite occurring in the eastern part of the area is traversed in all directions by thin veins of pegmatite. These ramify and send out branches which profusely cut the parent anorthosite just in the same way as a pegmatite cuts the parent granite. The contact is generally sharp but the veins frequently splay out as numerous thinner ones which end rather abruptly. There is every gradation from

these thin pegmatitic veins to broad bands and dikes. The latter have pink colour on account of the presence of large pink feldspars. They generally have the same trend as the rough foliation of the anorthosite, but cross-cutting relations have also been noted as in the Chouphari valley south-east of Laggadanga. Here the prevailing east-and-west strike of the anorthosite masses curves round to a north-east and south-west direction, but the pegmatite dikes run from north to south.

Dikes of dark hornblendic rocks are also very common but they do not ramify in the same way in the dark anorthosite as they do in the white variety. Like the pegmatite dikes these have a twofold relation to the anorthosites, *i.e.*, though they have the same general east-to-west strike of the anorthosite outcrops, cross-cutting relations are not uncommon.

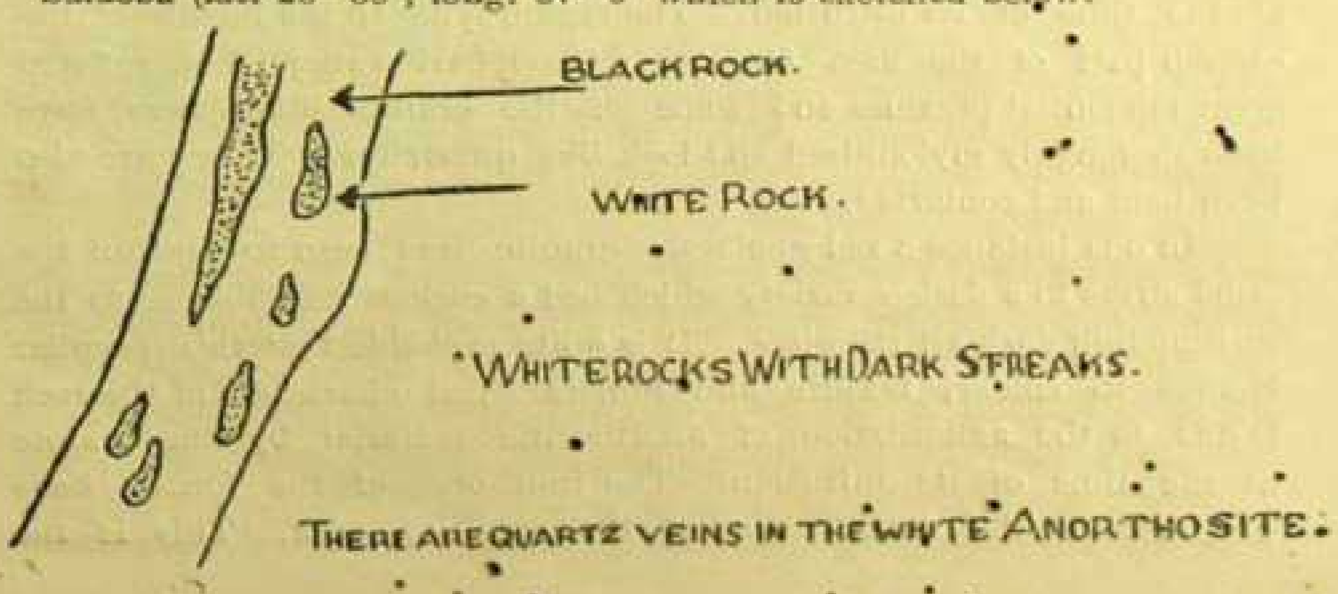
Anorthosite Gabbros.

This group includes rocks which contain a greater amount of femic minerals than the preceding types. They are comparatively infrequent and only a few isolated occurrences within the mass of the dark anorthosite have been noted, north of Mochrakend and south of Dang Mejia. Pyroxenic varieties occur as dikes in the western part of the area near Indrabil and Santuri. The rocks are distinguished in the field by their dark bluish colour and the presence of large serpentinised femic minerals. Microscopic examination has shown that the latter are olivines.

Granulitic Gabbros.

The occurrence of dark-coloured granulitic rocks in the anorthosites as schlieren, dikes and intrusive lenses, has been already noted. These occur throughout the anorthosite body and also in the adjoining crystalline terrain. As a matter of fact most of the low hillocks (either within or outside the anorthosite area) in the northern part of the district of Bankura and the adjoining part of Manbhum are made up of these hornblendic rocks. The dikes form characteristic ridges as they are more resistant to weathering than the intruded rocks such as anorthosite or granite gneiss. The rocks are hard, uniformly fine-grained and have a trap-like appearance. The weathered varieties are often jointed; foliation is generally absent, but there are instances where the rocks have been converted into hornblende gneisses and amphibolites. Some of these are also garneti-

ferous. Variations are found in the texture of these dark rocks ranging from fine-grained granulitic varieties to coarse-grained massive ones. Most of the dikes have an east-to-west trend with slight variations and sometimes the strike is north-west to south-east. It should be noted that this east-to-west strike of the dikes coincides with the strike of the anorthosite masses and with the direction of foliation of the older gneisses and schists. The dikes are not always vertical and where they are inclined the dip is always towards the north. Usually the dikes have clear-cut junctions with the anorthosites, but there are instances where they appear as small lenses and irregular sheets with ill-defined terminations. The contact wall shows evidence of deformative movement (see plate I, fig. 2). They may occur as thin sub-parallel bands close to each other in the mass of the labradorite rock and then the rock looks like a banded gabbro. This again may be cut by white granite veins and the whole complex is sheared and contorted or simply foliated. The direction of foliation is parallel to the strike of the dikes, though local variations are found. In the neighbourhood of the dikes the percentage of the dark minerals gradually increases towards the dikes and the junction actually is transitional. (See plate I, fig. 3.) These black bands grade into still finer schlieren and the resulting rock looks like a streaky anorthosite or an anorthosite gabbro transition rock. Within the mass of the black bands again there are fine streaks and veins of the white rock. A beautiful instance is found in the stream behind Saldoba (lat. 23° 30′, long. 87° 5′ which is sketched below.



This sort of intimate association of anorthosite and the gabbro has been noted in other parts of the area. The two rocks interpenetrate each other in such a way that it seems as if both have intrusive relation to each other. But the probable explanation is that the dark rock began to solidify earlier and caught up portions of the feldspathic liquid which appear as white streaks, veins and bands.

The massive and compact hornblende dike rock south of Santuri (lat. 23° 31′ 30″, long. 86° 51′ 30″) was found to be intersected by quartz veins and a dike of the normal granulitic rock is similarly cut by pegmatite veins near Jemua.

Granites, Granodiorites and Grano-anorthosite.

Perhaps the most interesting group of rocks in the area under study, besides the anorthosite itself is that of the granite and allied rocks. The commonest type is a pink rock whose colour is due to the presence of red or pink feldspars. It has a gneissic appearance due to the alternate arrangement of the quartzitic and feldspathic bands. The pink granite or granite gneiss always occurs as dikes and has the same trend as the foliation of the anorthosite. It occurs in many places and in certain sections leaves no doubt about its intrusive nature, as for example in the outcrop south of Dang Mejia. Some of the dikes are inclined towards the north. The granite cuts across the foliation of the anorthositic masses in the western part of the area but this relationship is only occasionally seen in the eastern part. In the former the granite is rich in epidote and is not gneissose. The foliation of the rock in the eastern part is considered to be primary, induced at the time of its intrusion. The region lying in the middle of the eastern part of the area (near the Chouphari valley) has suffered great tangential pressure and some of the granite dikes here have been thoroughly mylonitised and look like quartzites. They have also been bent and contorted.

In one instance a red gneissose granite was seen to pass in the same strike to a darker variety which had a curious resemblance to the surrounding dark anorthosites. It is quite probable that this peculiar change in colour, texture and mineralogical characters of the rock is due to the assimilation of anorthositic material by the granite at the time of its intrusion. The iron ores of the former have given rise to the dark colour of the resulting rock. This is the

only isolated instance of hybridism which the author has found during the long period of field work and he is constrained to consider it as the result of assimilation of anorthosite by granite. It cannot be regarded as a transitional rock because it is the only one instance of its kind.

There is again another group of granitic rocks which have such a superficial resemblance to anorthosite that there is likelihood of one's mapping them as anorthosite, unless one is very cautious in the field, especially when microscopic examination cannot be made while mapping is in progress. These occur as schistose and crushed zones within the anorthosite and a careful examination shows that they have a slight pinkish tinge. They end rather abruptly, being lost in the anorthosite mass. Microscopic examination has revealed that the rock contains an appreciable percentage of plagioclase of less calcic type than labradorite and hence it is a granodiorite.

Besides the above two types, there is a third type of granite in which the feldspars are white and usually form 'augen.' White 'augen' granites of this type have been noted in a few localities along the northern part of the anorthosite mass, west of the Ranigunj-Bankura road. The rock is garnetiferous. North of Matabail there is a good exposure where this garnetiferous augen granite is cut by bands of the dark granulitic gabbro. The strike of both these rocks shows considerable distortion. This shows that the gabbro dike was intruded subsequent to the intrusion of the augen granite. It is difficult to establish a correct sequence of the different intrusives, but there is no doubt that the dark amphibole rock which occurs as bands, is younger than the epidote granite. The epidote granite in the stream section behind Saldoba is invaded by this dark rock. The materials of the dark gabbro crystallised earlier than the felsic constituents and hence occur also as schlieren in the sheared granodiorites.

Pegmatites.

Finally, mention must be made of the pegmatite veins the mode of occurrence of which has been already noted. They are the final products of the differentiation of the original magma and have cut all the other differentiates. They are more abundant in the eastern part of the area.

Except the grano-anorthosite and the granodioritic granites, all the other types have also been noted outside the anorthosite belt, such as the granulitic gabbros and the hornblende gneisses. There

is another type of granite gneiss within the anorthosite, which closely resembles the granite gneiss of the surrounding country. It has the appearance of an intrusive, but an examination of its contact with the anorthosite, its texture and its physical appearance indicate that it is only a remnant of the country rock (see plate II, fig. 1). A beautiful example is seen north-east of Kustulia (lat. 23° 28′ 30″, long. 87° 5′ 30″). The country rock in the immediate neighbourhood is exactly of the same type and forms well marked ridges on the west side of the road to Saltora from Kustolia.

Anorthosite dikes.

Instances of anorthosite dikes are not common in geological literature. Except in California, where Miller (Miller, 1932) has recorded the occurrence of a number of anorthosite dikes of varying width, there is no other occurrence of anorthosite in the world where dikes are fairly abundant. In the area under study, several such dikes have been found in the country rocks surrounding the anorthosite mass. On the eastern side there is no contact with the country rocks and the anorthosite body abuts against the broad basin of the Damodar river. All the three varieties of anorthosite rock, *i.e.*, the white type, the dark type, and the gabbroid type, are represented. Of these the first type is more common. These dikes are fairly abundant in the region lying to the south-west of Kustolia at a distance of only about a mile. Here the anorthosites form ridges made up of tall slabs of compact rock which dip at high angles towards the north. The strike varies from east and west to east-south-east and west-north-west, parallel to the direction of strike of the intruded granite gneiss. Other less conspicuous dikes of anorthosite also occur between the main outcrop and the road. The anorthosite in all these exposures has a gneissoid appearance due to the parallel orientation of the constituents. The direction of orientation is generally from east to west. East of Barkona a succession of anorthosite dikes and the Bengal gneiss is found. Both these rocks are again intruded by the dark gabbro which has been converted into a hornblende gneiss. These dikes vary greatly in thickness ranging from a few feet to several yards. The anorthosite in these localities is of the white feldspathic type.

Dikes of anorthosite-gabbro have been found near Indrabil, cutting through the gneiss. In some places these dikes carry with

them contemporaneous bands of granulitic gabbro, as is well seen in the exposure behind the inspection bungalow of Saltora (lat. 23° 31′ 30″, long. 86° 56′ 15″). The anorthosite here has intruded into a hornblendic gneiss of Dharwar age which in its turn occurs as an inclusion in the granite-gneiss. The anorthosite is of a white type and the black bands give rise to sharp contrast (plate II, fig. 2). Further south the anorthosite is found to cut the granite gneiss and is itself cut by still younger quartz veins. It has assumed the foliation of the intruded gneiss, but the junction is quite distinct (plate II, fig. 3). At one place this gneissic country is traversed by a number of pegmatite and quartz veins with a thin band of plagioclase rock. This band has all the characters of the white anorthosite and there is no reason to doubt that it is the result of the intrusion of anorthositic material. (Plate II, fig. 4.)

Besides the anorthosite dike, a few dikes of oligoclase rock (oligoclasite) were found near the Sirjam railway station. Here the country rock consists of an interbanded series of sillimanite gneiss and feldspathic gneiss. Dikes of the dark gabbro and white granite are also found, the latter also cutting the oligoclasite. But the dikes here run north to south instead of east to west, parallel to the strike of foliation of the country rocks, which is here north-and-south. Some of the oligoclasite dikes are inclined, and dip towards the west against the feldspathic gneiss. They have a general resemblance to the anorthosites of the white type, but are more fine-grained.

Country rocks.

The country rocks occurring round the anorthosite mass, and to which the anorthosite shows distinct intrusive relationship, can be classified under two groups, namely those belonging to the Dharwars and those belonging to the Bengal gneiss group.

The latter includes gneisses of different types intruded by dikes of younger granites, hornblende rocks, pegmatites and quartz veins. The former is intruded by the gneiss and includes such types as hornblende gneiss (spotted), biotite-sillimanite schist, sillimanite gneiss and sillimanite quartzites.

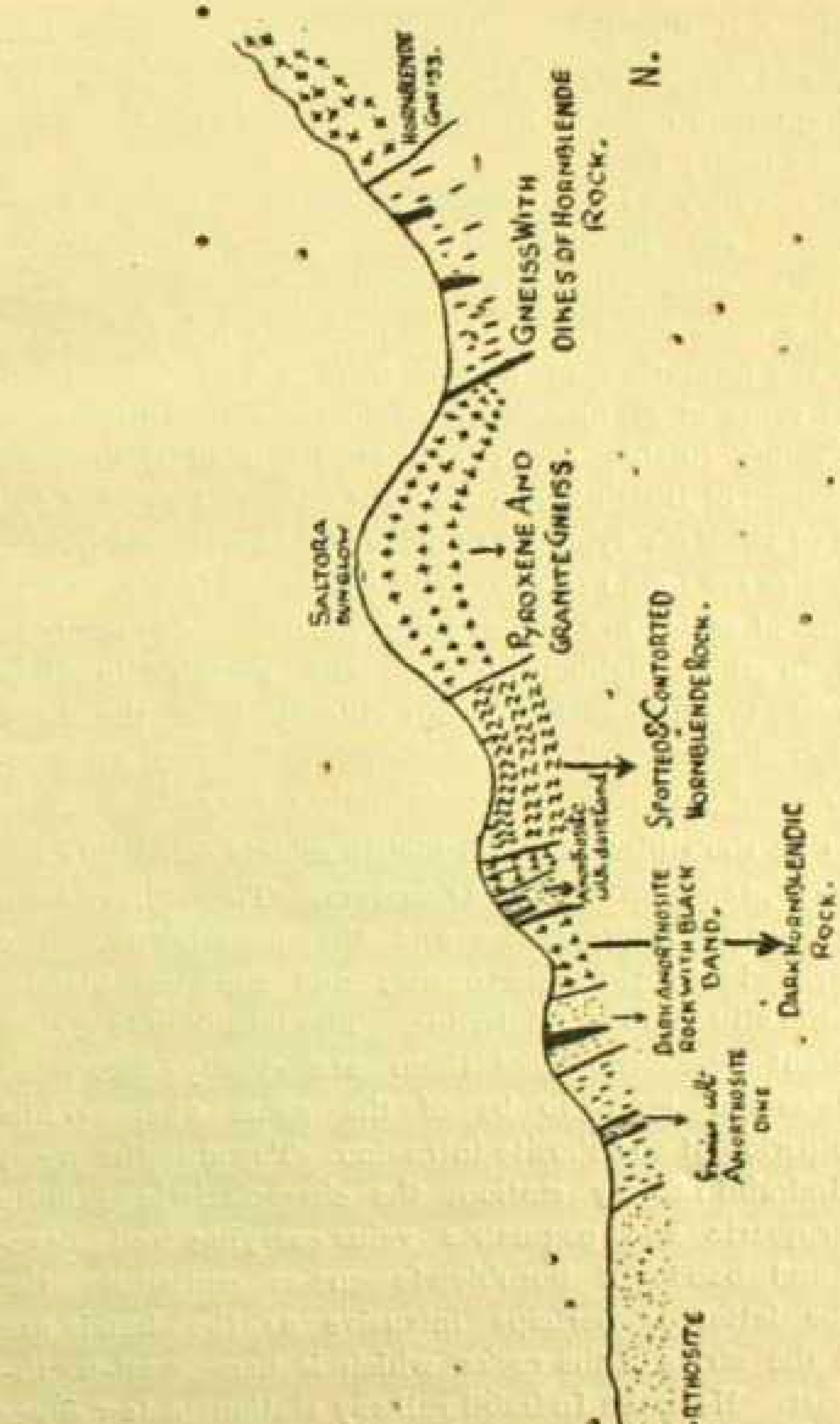
Starting from the eastern part of the area lying to the north of the anorthosite mass, we first come across sandstones of Panchet and

then of Raniganj age, faulted against the anorthosite. The older gneisses are first seen in the hills of Pabra (lat. 23° 32′, long. 87° 1′ 30″). The easternmost hillock is made up of the red granite and hornblende rock, but the other hills consist of feldspathic gneiss and pyroxenic gneiss. The latter forms most of the hills lying along the northern border of the anorthosite towards the west. It is interbanded with the Bengal gneiss, which is however characteristically found in the low grounds. The strike of the foliation of these pyroxenic rocks is remarkably constant and vary slightly from east to west. East of the Saltora inspection bungalow several inclusions of the Bengal gneiss are found in the anorthosite.

Mention has been made of the occurrence of hornblende gneiss (spotted) as inclusion in the Bengal gneiss behind the Saltora bungalow in connection with anorthosite dikes. The diagrammatic section on the opposite page shows the relationship of the different rocks.

The hornblende gneiss is a pale green phyllitic rock with large hornblende individuals which give the rock a spotted appearance. It is finely laminated and the laminæ are much contorted and folded. It resembles the hornblende-garbenschiefer of the German petrologists (Harker, 1932, p. 269) and has resulted from the regional metamorphism of Dharwar sediments.

West of Saltora pyroxenic and feldspathic gneisses prevail, the former making up most of the hill masses which occur to the north of the road. It varies from a fine-grained dark-coloured type to a coarse-grained feldspathic type in the same mass. The direction of foliation is east to west. An intrusive band of coarse-grained anorthosite was found in the foreground of the hill behind Santuri. There are phenocrysts of blue plagioclase in a white ground mass. The rock is foliated parallel to the foliation direction of the gneiss. South of the road near Santuri the rocks are granite gneisses of the type met with near the southern boundary of the anorthosite mass near Kustulia. East of Salbera there is a ridge of black hornblende rock. Within the anorthosite proper there are dikes of a flaggy hornblende schist and epidote granite, the former conforming to the foliation direction of the gneiss, while the latter cuts across the foliation and runs north to south. Besides these there are also quartz veins and pegmatites. Towards the west the strike of the granite gneiss veers towards a



(Approximate Scale 1" = 100'.)

north-east to south-west direction. The anorthosite outcrop here thins out gradually and completely disappears west of longitude 86° 50′. Throughout this long outcrop the anorthosite masses have the same strike as that of the country rocks.

In the Dangra valley to the south, rocks of different types and geological ages are interbanded such as white granite, phyllite, garnetiferous mica schists and sillimanite gneiss. Both the phyllite and the mica schists have been profusely injected by the granite resulting in the formation of a composite schist with innumerable streaks and veins of granite. Dark-coloured sillimanite gneiss crops out in the valley further south and are intruded by the pink feldspathic gneiss. South of Bhatuikhend (lat. 23° 26′ 30″, long. 86° 49′) dikes of anorthosite of the dark type, dark-coloured anorthosite-gabbro and hornblende gneiss are found in the pink gneiss. Massive hornblendite dikes, some of which are full of pink garnets, also occur in the Dangra valley in the neighbourhood of the anorthosite dikes stretching north-west to south-east. In an outcrop near the bank of the stream another instance of the interbanding between anorthosite and the dark-coloured granulitic gabbro is again observed.

It seems clear that the sillimanite and biotite schists constitute the oldest rocks of the area, representing the Dharwars. These have been intruded by the Archaean granite gneiss and the anorthosite. The granite gneiss is intruded by the anorthosite, and the hornblendic rocks, followed by the still younger dolerites. The hornblende gneiss seems to be of different ages. Some of them are closely associated with the granite gneiss and seem to be of the same age. While others belong to the period of anorthosite intrusion. Towards the west, *i.e.*, towards the Indrabil railway station, the characteristic granite gneiss with irregular quartz and pegmatite veins carrying well developed tourmalines and bands of hornblende gneiss constitute the country rocks. The latter is perhaps intrusive as the bands are oriented parallel to the strike of the rocks, which is here west-north-west to east-south-east. Near the Indrabil railway station, a few dikes of anorthosite were found near the abandoned lime-works. West of Jagannathdih a huge dike of dolerite was seen running for a long distance from the north-north-west up to Parbedia in the south-south-east.

Towards the south the country rocks continue to be sillimanite gneiss and a micaceous feldspathic gneiss, generally very much decomposed. Near Tuldoria the ground rocks are intruded by dark-coloured garnetiferous hornblende gneiss. Sillimanite gneiss constitute the country rocks in the regions where exposures are found, such as near the railway track and in the stream sections. The east-to-west strike of the rocks is found here to have changed into a north-to-south one. The change from an west-north-west east-south-east strike, to a north-west south-east strike was first noticed in the Dangra valley near Pathardiha (lat. 27° 26′, long. 86° 48′ 30″) but within a distance of about five miles towards the south-east (near Bardiha) the strike changes from north-west south-east to north-south. The gneisses are here intruded by massive dikes of a finely crystalline white rock which in hand specimens looks like anorthosite but on microscopic examination has proved to be oligoclasite. Besides the white rock there are also dikes of the dark hornblende gneiss which form fairly prominent ridges in an otherwise rolling country. The oligoclasite dikes show sharp contacts, inclined towards the west against the feldspathic gneisses. The trend of all these dikes is parallel to the strike of the foliation of the gneisses and they dip towards the west. Dikes of white granite with the same trend occur sporadically and at one place south of the railway they cut through the oligoclasite. This granite is therefore the youngest of all the intrusives.

West of Sirjam railway station the country rock is a micaceous granite gneiss into which there are intrusions of white oligoclasite and white granite with well developed tourmaline. Further down the Dangra valley up to its confluence with the Adali, the rocks consist of an interbanded series of granite gneiss, hornblende gneiss, and sillimanite and quartz sillimanite gneiss. Their strike varies from north and south to north-north-east and south-south-west and the dip is as before towards the west. The quartz sillimanite gneiss forms massive hillocks in this place and extends across the railway line towards the south. In the interior, *i.e.*, towards the north-east there is no occurrence of anorthosite until the main outcrop is reached near Shiarbedia. Away towards the interior exposures of rocks are few and far between, hidden by a thick yellowish soil, but the few scattered outcrops show that the country rocks consist of granite gneiss cut

by hornblende gneiss. The latter forms ridges and hummocky masses. The characteristic east-west strike of the foliation observed in the region north of the anorthosite outcrop is again regained here, but in the south-west near the B. N. railway and in the Gandheswari valley the gneisses strike between north-north-west and north to south-south-east and south. The dip is also variable. Bands of pegmatitic granite with pink feldspars are found here and there. The Susunia massif consists of bedded indurated sandstones assigned by Ball to the Cuddapah system.

In the Dhapali Jhor, north-east of Susunia, a good section illustrating the nature of the country rocks is seen very near the motor road. The rocks run across the river bed from the north-north-west to the south-south-east dipping towards the north-east. These consist of an interbanded series of quartzo-feldspathic gneisses and hornblende schists. Both are very much contorted and the latter seem to suggest strongly a sedimentary origin, in the presence of numerous light quartzo-feldspathic veins and stringers alternating with thin hornblendic bands.

Further along the motor road the strike of the country rocks resumes the direction east-south-east to west-north-west, similar to the direction observed in the north-west, north of the anorthosite mass. East of Barkona (lat. 23° 27′, long. 87° 4′) from the 12th mile-post a number of dikes of the white anorthosite is seen to cut through the gneiss along the foliation planes, and stand out prominently in vertical ridges. The anorthosite in all these exposures has a gneissoid appearance, due to the orientation of the constituents, parallel to the foliation direction of the country rocks and the direction of elongation of the dikes. Dikes of a fine-grained quartzitic rock also occur in the same way as the anorthosite. The granite gneiss is not so much decomposed as in the western part of the area, and tall vertical tors of the gneiss form characteristic ridges which run parallel to the anorthosite dikes. Near Narainpur (lat. 23° 28′, long. 87° 5′) further along the road towards the north-east, dikes of anorthosite and hornblende gneiss are again noted in the granite gneiss. As has been already pointed out the hornblende gneiss in the country rocks does not seem to be of the same period of intrusion as the anorthosite and careful observations were made to find out if it

were not even older than the basement gneiss. All doubts about this were set at rest by the examination of the stream section, south-east of Kustulia inspection bungalow (lat. 23° 28′ 30″, long. 87° 5′ 30″). Here the hornblende gneiss was found occurring as dikes and lenses in the gneissic basement. The strike of the foliation bends round the hornblende gneiss and the lenses pinch out at the ends in such a way that it seems more reasonable to suppose that the material of the lenses has forced open its passage through the gneisses, rather than that these hornblende gneisses are inclusions in the granite gneiss. The intrusive character of the hornblende gneiss is also borne out by the nature of the numerous dikes. The granite gneiss is of the same type as has been already noted near Saltora and has similar appearance on weathered surfaces. There are pegmatite veins in both the hornblende gneiss and the granite gneiss, as also along the junctions of the two. The strike of these gneisses is approximately east to west or east-south-east to west-north-west.

From Kustulia a road runs up to the Saltora dak bungalow (lat. 23° 31′ 30″, long. 86° 56′ 15″). A short distance up along this road there is a stream in which ridges of granite gneiss with subordinate bands of hornblende gneiss are again observed. The granite gneiss (Bengal gneiss) found in all these localities near Kustulia has a marked resemblance to that found near Santuri, but differs in physical appearance, particularly in weathered specimens and in mode of occurrence, from the gneisses found along the northern boundary of the anorthosite near Saltora. This granite gneiss extends towards the west from the Kustulia-Saltora road, and is intruded by hornblende gneiss and also anorthosite, as has been already noted near Barkona and Narainpur. Granite gneiss prevails towards Saltora and forms characteristic ridges which generally run east and east-south-east to west and west-north-west. These ridges are quite abundant near Chatturpathar (lat. 23° 29′, long. 87° 4′). The granite gneiss has a pink colour but is cut by bands of younger granite with white feldspars. Within the anorthosite mass lying to the north-east of the Kustulia inspection bungalow, there is a long ridge of granite gneiss similar to the gneiss noted above. No definite intrusive contact was found and the alignment of the ridge is not regular (see plate 2, fig. 1). The junction between the two rocks is in most places hidden by alluvium. In the light of the structural

relations between the gneiss and the anorthosite as revealed near Narainpur, it seems clear that this ridge of granite gneiss is a remnant of the country rock. It has the same east and east-south-east to west and west-north-west strike and dips towards the north.

On the Bankura-Raniganj road a much decomposed hornblende gneiss is first met with, south of the anorthosite mass near Ghotkargaon (lat. 23° 29′, long. 87° 11′). A dioritic rock occurs near Nandanpur further to the south, but gneiss with white feldspar forms the chief country rock. Other rocks found here and further on towards the north-north-east are quartzites, pink gneisses, augen gneiss and graphic granite. Another instance of the occurrence of the older Bengal gneiss as a dikelike inclusion in the anorthosite is found near Bindabanpur (lat. 23° 30′, long. 87° 14′).

The dikes of younger intrusive rocks found in the area belong to two types, namely dolerite and lamprophyre. The former cuts through the anorthosite just south of the Gondwanas near Jemua (lat. 23° 34′, long. 87° 4′ 30″) where also occurs the lamprophyre. The former runs north to south, but the latter cuts through the Archaean gneisses in an east-west direction, south of Jemua. Dolerite dikes have also been found in the anorthosite near Saragdih (lat. 23° 32′, long. 87° 5′) and in the gneisses near Parbedia (lat. 23° 26′, long. 86° 48′ 30″). The youngest rocks of the area are of course the pegmatites (other than those found associated with the anorthosites), graphic granites, schorl rock and quartz veins which cut the gneisses surrounding the anorthosite body.

It may be mentioned here that granite gneiss of the type described from this region extends towards the north-west and forms the basement rock of the region round Adra. Here this gneiss is intruded by huge masses of a porphyritic granite which forms characteristic dome-shaped hills and rugged cliffs such as those found near Bero (lat. 23° 32′, long. 86° 45′ 15″). Here the gneiss is also intruded by a dark hornblendic rock which resembles the gabbros associated with the anorthosite. The similarities in physical character are borne out by the microscopic characters. The occurrence of these gabbro dikes as also the anorthosite dikes, far away from the main anorthosite outcrop, indicates that the anorthositic rocks underlie the gneiss in some parts of the surrounding country, in spite of the tremendous extent of erosion which the region has undergone.

VI. Petrographical Notes on the Chief Groups of Rocks and the Country Rocks

Labradorite rocks.

These monomineralic rocks consist essentially of plagioclase with a very small amount of femic minerals. Though there is no marked difference in physical appearnce between different specimens of these rocks, certain varieties can be made out from a study of the thin slices. The rocks are characterised by granulitic texture, but whereas in some, the minerals are equidimensional, in others large porphyritic individuals are seen, surrounded by, and set in, a coarse to finely granulitic base. Marginal protoclastic granulation is common, but in many sections the anhedral feldspar individuals occur in perfect juxtaposition without granulated margins. (See plate III, figs. 1 and 2.) Under crossed nicols the larger individuals often show beautiful schillerisation, and in the position of extinction appear full of shining wisps of a micaceous mineral with a roughly parallel arrangement. The smaller individuals do not generally show this phenomenon. According to Adams (1885, p. 85) these inclusions disappear in the Canadian anorthosites, when the feldspars are granulated. Though this is seen in most of the larger individuals, it is more common in the untwinned ones and in sections parallel to 010. (Plate III, figs. 4 and 3.) Besides occurring as micaceous wisps, the inclusions occur as dark rods and plates and as numerous black dots arranged in parallel lines which give the mineral a dusty appearance. These unite to form small masses of ilmenite and so they probably belong to titanic iron ore. The semi-transparent micaceous variety belongs to the type of micaceous titanic ore of Rosenbusch. The feldspars of the darker anorthosites contain a larger amount of these inclusions, on account of which they have the dark grey appearance. Though the feldspars are mostly twinned, untwinned feldspars characterise certain varieties. Twinning on Albite law is more common, but both Albite and Pericline twinning occur in the same individual. Combined Carlsbad and Pericline twinning has also been noted, the extinction angle of the former indicating a basic labradorite. The twin lamellæ are generally imperfectly developed and do not extend over the entire section. They are bent and twisted and the extinction is not uniform. When schiller inclusions occur in

twinned feldspars, it has been noted that one set of the inclusions is parallel to the twinning planes while the lines of the other set make angles of 45°, 54° or 65° with the former. Cleavage lines are clearly seen in some. Extinction angles measured from the cleavage traces parallel to 010 give angles of 37°, and the average value of the maximum extinction angle in the zone normal to 010 measured in numerous sections from different varieties and localities is 37° which indicates a composition with more than 65% An. Measurement from the traces of 001 cleavage indicates, sometimes a composition with 60% An. Detailed study with the Federov stage is in progress and the results will be published later on. The average refractive index estimated from a number of thin flakes, is about 1·559, *i.e.*, the same as that of monobromobenzol. In sections showing porphyritic feldspars, the granulation is usually well developed along certain zones, and when the rock carries femic constituents, the latter also occur in these zones. Protoclastic granulation is common in these porphyritic types and all the stages from a clear outline, through crenulated margins, to a marginally granulated stage are seen in different sections. (Plate IV, fig. 1.)

The anorthosites occurring as dikes have a gneissic appearance due to the alternate arrangement of the feldspar bands with the ferromagnesian streaks. The dike rock of Narainpur is of this type, but the rock near Santuri shows in hand specimens the presence of large pieces with well developed cleavages, embedded in a fine-grained white matrix. These large pieces are oriented parallel to the direction of the foliation of the country rocks. When the main mass of the anorthosite does not show any foliation,* it is reasonable to suppose that the foliation in the dikes is due to the influence of the foliation of the country rocks.

Alteration of the feldspars is of the same type in specimens from different localities. Kaolinisation is generally seen in the surface rocks, but in fresh specimens the alteration is along the edges of the minerals or sometimes in the interior of a mineral. The chief alteration products are, sericite, muscovite, epidote, calcite, chlorite (penninite with ultra blue interference colour), sphene and

* Foliated types have been found locally only near the margins.

scapolite (dipyrite and mizzonite). According to Clarke (1920, pp. 600-601) epidotisation represents a reaction between feldspar and the femic constituents which releases quartz, while scapolitisation requires lime which is liberated during the change of pyroxene to amphibole. Lime and silica from the feldspars combine with the titanium of ilmenite to produce sphene. Small quantities of these femic constituents are present in most of the anorthosites. The chief femic constituents are: pyroxene (both monoclinic and rhombic), amphibole, biotite, ilmenite and garnet. These seldom exceed 5% of the total quantity of minerals. These are not uniformly distributed in the rock but generally occur in clusters. Biotite and hornblende usually occur together and both may surround pieces of ilmenite. Biotite sometimes completely surrounds the ilmenite and may be intergrown with it (plate IV, fig. 2). Sederholm (1916, p. 2) has given several instances of the " formation of biotite at the boundary of plagioclase and ore in diabases and gabbros." The biotite occurs between the ilmenite and the plagioclase, and has probably originated by a reaction between the two minerals during post-magmatic stages when volatiles were more abundant. Biotite has brown pleochroism, and is generally fresh. In some specimens it has altered to penninite. The primary hornblende has the following pleochroism, X—yellow, Y—bluish green, Z—greenish blue, or, X—yellowish green to Z—dark green. In some rocks both biotite and hornblende have been chloritised. The pyroxenes, both rhombic and monoclinic, occur as large individuals and also as small granulitic aggregates. They are schillerised and show different stages in amphibolisation. On amphibolisation the schiller inclusions are thrown out towards the periphery, where they coalesce together into granules of ilmenite. The rhombic pyroxene is faintly pleochroic and the bluish green colour of the rhombic variety is exactly similar to the same colour of the monoclinic one. Within an aggregate of granulitic pyroxenes some show the pleochroism of hypersthene, but otherwise in respect of cleavage, schiller inclusions and colour, all seem to be of the same type. The rhombic pyroxene often shows inclined extinction, and the angle may be as high as 18° or 20°. The monoclinic pyroxene is in some specimens altered to bastite. Garnet does not occur in all the specimens, nor do the specimens in which it occurs show the slightest

Dark Anorthosites.

evidence of dynamic metamorphism. It has the same light pink colour as that of the rhombic pyroxene. It does not show any reaction rim but is spongy in appearance and contains numerous inclusions of quartz, feldspar and amphibole. Narrow bands of amphibole occur between adjacent garnets. It seems that the garnets have formed at the expense of pyroxene, the relic pyroxenes having been subsequently altered to amphibole. The same phenomenon has been observed in the basic charnockites of South India (Holland, 1898, p. 161).

Ilmenite occurs without exception in all the slices, varying in size from large irregular pieces to minute dustlike inclusions. West of Saltora thick masses of ilmenite occur near dikes of the dark gabbro.

Zircon is very rare in the anorthosites and apatite has not been found. Quartz occurs interstitially in some. In the Chouphari stream section below the bridge on the Raniganj-Bankura road, slices of the anorthosite containing basic schlieren show the presence of a considerable amount of quartz (plate IV, fig. 3).

A peculiar dike rock was found near Barkona within the Bengal gneiss which resembles the Anorthosite in physical appearance but is rather quartzitic. Microscopic examination shows that it is a granulated quartzo-feldspathic rock with abundant particles of biotite disseminated throughout the slice. Both orthoclase and plagioclase (labradorite) occur, and one or two large individuals of schillerised plagioclase are noted. The other constituents are muscovite and hornblende with a pinkish violet colour (arfedsonite). The rock may be co-magmatic with anorthosite, and may represent an acid end stage. Mention may be made here of the schistose and sheared bands of a rock resembling anorthosite, occurring within massive anorthosites which, on microscopic examination, proved to be crushed granodiorites.

The specific gravity of the labradorite rocks is 2·69, and that of the dark anorthosite is 2·72.

Oligoclasite.—This rock is lighter than the labradorite rocks and has a specific gravity of 2·63. In hand specimens it is a fine-grained white rock with granular texture. Microscopic examination shows the presence of acid plagioclase (oligoclase) and a much greater degree of kaolinisation than in the case of the labradorite rocks. The femic

minerals such as ilmenite, pyroxene, and biotite have also been altered. Epidote and chlorite have largely replaced the feldspars and the femic constituents. The chlorite has a pleochroism from pale yellow to green and has ultra-blue birefringence. It is a positive penninite.

The dark-coloured anorthosites grade into a gabbroid type in some places such as near Mochrakhend (lat. 23° 31′, long. 87° 9′) and Mejia (lat. 23° 33′, long. 87° 8′ 15″).

Anorthosite Gabbros.

In the field these can be distinguished from the dark anorthosites by their darker colour, coarser grain and by the presence of altered femic minerals such as olivine and pyroxene. In these rocks the plagioclase (labradorite) assumes large dimensions with beautiful schiller inclusions. These are fringed by smaller equidimensional individuals, and by anhedral flakes of biotite and granules of hornblende and pyroxene. The pyroxenes are schillerised. Large pieces of olivine are found with well developed reaction rims. The mineral is generally serpentinised and is enclosed subpoikilitically by the plagioclase. Serpentinisation has proceeded along cracks which extend across the minerals forming the reaction zones. The reaction rims consist firstly of hypersthene with characteristic pleochroism and low polarisation colour, followed by enstatite with lower polarisation and then by garnet. Sometimes there is a narrow zone of feldspar between the pyroxene and the garnet, and the garnet is spongy with numerous small inclusions of quartz and amphibole. The pyroxenes have been amphibolised along their outer margins. (See plate IV, fig. 4.) According to Bowen and Anderson (1914, pp. 481-500), olivine crystals are resorbed with the development of reaction rims of enstatite, during the normal crystallisation of a basaltic magma. By further recrystallisation due to subsequent metamorphism the mineral has become granulitic. Kemp (1894, p. 221) has described similar reaction rims around olivine in the gabbros of Lake Champlain. Adams (1885) has described rims of rhombic pyroxene and hornblende, round olivine in the anorthosites of Saguenay. These reaction rims always occur between the olivine and the feldspar. Other instances have been recorded in the peridotites of the Cortlandt series (Williams, 1886), in the Lizard gabbro (Teall, 1888), and in the norites of South India (Holland, 1896).

The formation of garnet at the expense of pyroxene is well seen

in this rock. Possibly there has also been a reaction between the pyroxene and the feldspar, according to the following equation of Hezner (1903) and Grubenmann (1910) :—

Diopside + anorthite = garnet + quartz.

The garnet in fig. 1 of plate V has numerous inclusions of amphibole and quartz. It occurs between olivine seen on the right and a band of hypersthene seen on the left. Amphibolisation in these rocks seems to have occurred later than the plutonic metamorphism under the conditions of which the garnet was developed.

The anorthosite gabbro dike occurring near Bhatuikhend (lat. 23° 26′ 30″, long. 86° 49′) has the composition of a norite, but it differs from the dark-coloured granulitic gabbro dikes in having a more coarsely crystalline texture. The feldspars are of the same type as found in the anorthosites and show beautiful schillers of micaceous titanic ore. The twin lamellæ are bent and contorted. Hypersthene is the most abundant of the femic constituents. It has not suffered any granulation, is full of schiller inclusions and has altered to amphibole particularly along the peripheries. Some are of the bronzite variety characterised by a sub-metallic lustre, lack of pleochroism and weak birefringence. The other minerals are brown biotite and ilmenite.

Dark-coloured granulitic Gabbros and Norites.

As has been noted previously in connection with the field relations and characters of these rocks, these granulitic gabbros vary in size from narrow schlieren to massive dike intrusions. They are very hard, compact, uniformly fine-grained and have a perfectly black colour with sometimes a greasy lustre. But sometimes these have developed a foliated structure and have been converted into amphibolites and hornblende gneiss. They occur outside the anorthosite outcrop, where sometimes they can be distinguished from the older hornblende gneiss by their peculiar greasy lustre and compact granulitic appearance. The foliated varieties are often garnetiferous. The non-foliated varieties have an uniformly granulitic texture, though there is considerable variation in the dimensions of the constituents. (Plate V, fig. 2.) In some granulation has taken place along certain zones. The principal constituents are plagioclase, pyroxene (both monoclinic and rhombic), hornblende, biotite, ilmenite, etc. In the schistose varieties the amphiboles have

attained large dimensions by the absorption of the materials of a granulitic aggregate of several pyroxenes and the schiller inclusions are thrown out towards the periphery. The light greenish tinge of both the monoclinic and the rhombic pyroxenes is strikingly similar, and both are schillerised. Hornblende develops after both. The rhombic pyroxene has inclined extinction.* It seems to be secondary and derived from the monoclinic pyroxene. Hypersthenisation of monoclinic pyroxenes has been observed in the Charnockite series of Cochin (Sen-Gupta, 1916) and of Uganda (Groves, 1935, p. 196). Some of the schistose varieties have again undergone a great deal of shearing, resulting in the comminution of the hornblende. The hornblende is thoroughly mortarised in these specimens. (Plate V, fig. 3.)

A number of microscopic sections of specimens from the junctions of the granulitic gabbros and the anorthosites were examined in order to find out the mode of origin of the former. This examination leaves no doubt about the correctness of the explanation arrived at from a study of the field relations. The junction is of course sharp in some places, but generally there is no distinct linear junction between the mineral fields of the two rocks and there is an interpenetration of the minerals belonging to the adjacent fields. (See plate V, fig. 4.) Slices of the banded anorthosite (with bands of the darker rock) show that the thin bands are really schlieren consisting chiefly of the femic minerals, such as pyroxene and hornblende together with ilmenite. In some sheared varieties, the schlieren are sheared, granulated and crushed. The shearing has taken place subsequent to the formation of the amphiboles which are frittered and mortarised. The amphibole has altered to epidote and chlorite. Epidote fills up the microscopic cracks in the rocks and is associated with sphene. The feldspars have also been granulated and the large relic feldspars indicate the size previously attained by the minerals. Some of the rocks are garnetiferous. In the banded anorthosites of Saldoba, garnets have attained very large dimensions in one part of the outcrop. The other minerals have also large dimensions, so that the rock is very coarsely crystalline. The

* Washington was of opinion that the minerals are "really rhombic, the apparent oblique extinction is due to the absence of prismatic cleavage and the development of cracks or cleavage parallel to the (010)b." Amer. Journ. of Science, Vol. 41, p. 331, 1916.

garnet has a pink colour and includes blebs of hornblende and biotite and is also fringed by these. Granules of ilmenite occur inside the garnet representing the schiller inclusions of the original pyroxenes.

In the gneissic variety, the paramorphism of both the pyroxenes is more complete, and due to the directed pressure the minerals show granulated borders and the feldspars show strain shadows and wavy extinction.

Besides the above, dikes of hornblendite and pyroxenite were also noted, the former behind Kustulia and the latter in the Dangra valley. The first rock originally consisted chiefly of hornblende, which has extensively altered to chlorite, epidote and sphene. The pyroxenite consists of pale green augite with well developed cleavage, changing into hornblende and garnet, with a small quantity of plagioclase feldspar. The garnet contains inclusions of hornblende. The pleochroism of the hornblende is as follows :—

X—Yellowish green Y—Olive green Z—Deep green.

These rocks appear to be extreme basic varieties of the granulitic gabbros. The average specific gravity of the granulitic gabbros varies from 3·11 to 3·2.

The gneissic variety of the gabbros resembles the older hornblende gneiss which occurs chiefly as dikes and lenses in the granite gneiss surrounding the anorthosite and varies from a plagioclase-pyroxene gneiss to typical hornblende gneiss. In the former the pyroxene passes into hornblende with pleochroism varying from brownish yellow to pale green or from brownish green to yellowish green. The plagioclase is of an acid type whereas it is always labradorite in the gabbros and the rocks contain an appreciable amount of quartz. Granulitic structure is also generally absent.

Granites, Granodiorites and Grano-anorthosites.

The mode of occurrence of these rocks has been discussed in the section under field relations. The granites belong to two types ; the one is characterised by the presence of pink feldspar, while in the other the feldspar is white and forms augen. The former is more prevalent. It has assumed a gneissose structure in most places.

Thin sections show the presence of a large amount of Deuteric (Sederholm, 1916) or Guttate perthites (Tom Barth, 1930), besides quartz, a small quantity of small plagioclase feldspars, and myrmekite in the granulated zone surrounding the perthites. The inclusions in the latter sometimes assume recognisable size with well developed twinning. Plagioclase is not always present and orthoclase with straight extinction on cleavage lines is present in many cases. Microcline is rare. There is a very small quantity of ferromagnesian minerals, such as green biotite and hornblende. The former is elongated parallel to the direction of foliation. When altered it passes into chlorite. Hornblende is altered into a fine aggregate of serpentine and muscovite. Other secondary minerals are epidote, muscovite, sericite and calcite. The accessory minerals are zircon and ilmenite. Epidotisation has proceeded considerably in some giving rise to a variety of epidote-granite. Epidote is primary in the sense that it formed under hydrothermal conditions.

The perthitic structure is not evident in all the sections, but is often revealed by the kaolinisation of the included plagioclase. The gneissic structure is due to the alternate and sub-parallel arrangement of the quartzose and the feldspathic bands. Quartz is clear, but the feldspars have wandering extinction, and have undergone a much greater degree of crushing and granulation in the crushed varieties.

The augen granite has suffered a great deal of shearing stress as is seen in the field and shows the effects of crushing in thin slices. Both plagioclase and orthoclase occur, and show undulose extinction. Large relic feldspars form 'eyes' enclosed by granulitic minerals. Myrmekite is present in this zone. The constituents have a parallel arrangement.

The intrusive nature of the granite is proved by the mode of occurrence of the dikes. Samples were taken from the junction between anorthosite and a pegmatitic variety of this granite. The contact zone is marked by the presence of granulated quartz and feldspar and a dark-coloured chloritic mineral occurring interstitially. The granitic portion shows large individuals of perthites. The plagioclase inclusions of these perthites form small drops or blebs and occasionally pass into veinlets. The drops have a lens shape and pass into elongated strings. Incipient microcline twinning is seen in some,

which are also bordered by a granulated zone carrying myrmekite. Biotite is altered to a greenish variety which has still the birefringence of mica. The anorthosite portion is not much granulated. It includes many diopside individuals which are often chloritised.

Granodiorites.

There is a common type of granite or more correctly granodiorite which occurs as schistose bands in the anorthosite. It has not been found occurring as a clear-cut dike-like mass and but for its light pinkish colour and foliated nature, it is indistinguishable from the anorthosite in which it occurs. In the field it was identified as a foliated type of anorthosite, until its real nature was found out by microscopic examination.

Under the microscope the rock is seen to have undergone much crushing. The minerals are arranged as alternate bands of quartz and feldspar. Both the minerals are elongated parallel to the direction of foliation. Quartz is clear and is without wavy extinction. Feldspars have numerous inclusions of shreds and patches of biotite, many of which occur along the cleavage cracks. The feldspars are much granulated, and occasional large individuals show the size attained by the minerals before crushing. Most of them are untwinned but some show an incipient microcline twinning. A few grains of plagioclase of the composition of oligoclase or andesine occur. (See plate VII, fig. 1.) Most of the specimens are very greatly crushed and some thoroughly mylonitised. In these, quartz forms parallel streaks elongated parallel to the direction of foliation. They are recrystallised. Feldspars are thoroughly mortarised; occasional relic feldspars show tattered edges and microcline twinning and the grains are bordered by myrmekite with sometimes a spherical form. (See plate VI, fig. 1, and plate VII, fig. 2.) It presents a convex surface to the microcline and corresponds to the description given by Becke (1908). A few grains of oligoclase and perthites also occur. These show strain shadows. Even the ilmenite grains are frittered, and the small granules have spread along the direction of foliation. Such is the case with the epidote granules. Secondary epidote and calcite are unbroken. The green biotite is elongated parallel to the foliation. Garnets have developed in some by reaction between biotite and quartz. The garnet is of a pink almandite variety. It occurs along the direction of foliation with a linear trend. Zircon is a constant accessory. Both magnetite

and ilmenite are present. The former has altered into hæmatite but the latter very rarely into leucoxene.

Sections of rocks taken from the junction between this granodiorite and anorthosite show a clear junction between the two. The plagioclase feldspars of the anorthosite portion have unbroken margins, but all the minerals of the other portion are granulated. Hornblende is associated with ilmenite and is also crushed. The crushing of this rock took place at the time of injection.

Though these granodiorite bodies show intrusive contacts, they always occupy sheared zones in the anorthosite and grade into the latter rather indistinctly at the ends. The compact anorthosite masses are traversed by a network of pegmatite veins which ramify and splay out at the ends. These facts seem to suggest that the material of the granodiorites and the pegmatites was derived from the same magma which produced the anorthosite masses, and that it subsequently invaded the earlier-formed rocks. In other words the occurrence of these granodiorite and pegmatite rocks as dikes and veins is due to a phenomenon of auto-intrusion, *i.e.*, intrusion of an earlier-formed rock by the still liquid or semi-liquid portion of the primary magma. The pegmatites represent liquid portions, but the materials of the granodiorite dikes were in an advanced state of crystallisation on account of which the rock is so much crushed and granulated, while the intruded anorthosite is unaffected. The mode of occurrence and the mineral composition ranging from granodiorite to pegmatite, are strong arguments in favour of the explanation given above.

But although the granodioritic material is supposed to have originated from the same magma, it might have formed at different depths and subsequently intruded the overlying rocks. That this actually happened is shown by the occurrence of the grano-anorthosite, reference to which was made in a previous section. Under the microscope the rock is seen to consist of all the minerals which characterise the granodiorites, but the plagioclase feldspars are of two different types, namely, oligoclase and schillerised labradorite. (See plate VI, fig. 2.)

The labradorite feldspars have all the characters observed in them in the anorthosites. The junction between these minerals and the rest of the granodioritic portion is irregular. These feldspars show more or less straight edges, but the granodioritic portion is as usual crushed,

with the formation of myrmekite and development of cross-hatching and undulose extinction in the alkali feldspars. Hornblende is altered to penninite, mica and epidote. The materials of the last-named mineral are derived from both hornblende and plagioclase feldspar. The occurrence of labradorite in this rock cannot be explained by any other hypothesis than that of hybridism. Miller (1918, pp. 437-45) has described the occurrence of similar hybrid rocks from the Adirondacks to which he gave the name "Keene-gneiss." But this idea has been disputed by Balk (1932), and Alling (1932) who regard the keene-gneiss as a transition rock between the anorthosite and the granite. Moreover the result of Bowen's experiments (Bowen, 1922) indicate that 'granite magma saturated with an acid plagioclase cannot dissolve basic plagioclase but can only react with it and convert it into more acid plagioclase.' In the present area of anorthosite no transition rock has been met with in spite of the most detailed field work and the dike, the rocks of which are under description, is the only one of its kind. If the material of this dike had been in a fairly advanced stage of crystallisation, it could not possibly react with the plagioclase feldspars of the anorthosite xenoliths it caught up, during its upward passage.

The specific gravity of the acid gneissose granite is 2·59, while the specific gravity of the granodiorite is 2·76 and that of the epidote granite is 2·98.

It should be noted in this place that like the anorthosite and the gabbro, the granites also occur as dikes within the country rocks surrounding the anorthosites in many places.

Compared to the large area covered by the anorthosite and by the gabbros, the granitic rocks are quite inconsiderable in extent and bulk. If the granites are due to a separate period of intrusion they should be expected to cover a large area. The small bulk also suggests a residual origin.

Country rocks.

Bengal Gneiss.—This is the most prevalent type of gneiss. It is generally of a pink colour and coarse texture. The specific gravity is also high, *e.g.*, 2·8. It is a typical microcline gneiss and agrees closely with the description of the Chota-Nagpur granite gneiss given by Dunn (1929). It consists of quartz; microcline perthite, orthoclase in small quantity

(plagioclase with antiperthite in some cases), biotite, hornblende, ilmenite and zircon. The perthite structure is beautifully developed. It is of the type of film perthite (see plate VI, fig. 3) of Anderson (1928). In some, large porphyritic individuals are set in a base consisting of granulitic quartz and feldspars. Myrmekite is well developed in these.

Quartzo-feldspathic Gneiss.—This rock occurs in many places along the northern boundary of the anorthosite near Saltora. It is much decomposed and is closely associated with pyroxenic and hornblende gneisses. The rock from Saltora has a granulitic structure as a result of crushing. There are alternate bands of recrystallised quartz and granulated feldspars. Occasional large pieces of feldspars also occur. Plagioclase of an acid variety is present. Myrmekite is noted. An interesting constituent is allanite, of which an isotropic variety is also found. Pleochroic allanite occurs in the Bengal gneiss found near Bindabanpur near the south-east boundary. The mineral is decomposed into a brownish isotropic substance. Small granules of clinozoisite are present. Iron ores are fairly abundant and these together with the granules of clinozoisite occur along parallel lines. These with the quartz feldspar bands give the rock its gneissic appearance. The iron ores are extensively altered to hæmatite, which has stained the rock and has filled up the cracks in altered specimens. Small biotite flakes occur abundantly with their longer axes parallel to the direction of foliation. Hornblende sometimes assumes large sizes and forms 'eyes.' The rocks as a whole have a quartzitic aspect.

Amphibolites.—These rocks occur near Saltora and are invaded by the gneiss noted above and also by the anorthosite.

Spotted Hornblende Gneiss.—It is really a crushed quartzite with a small amount of feldspar and large porphyritic hornblendes which were broken along their outer margins at the time of foliation. Small granules of hornblende and mica are scattered throughout the slide and are arranged along directions of foliation round the porphyroblasts of hornblende. (See plate VI, fig. 4.)

Pyroxene Gneiss.—These are plagioclase pyroxene gneiss with secondary hornblende. The pyroxene belongs to both the monoclinic and the rhombic varieties. The rhombic pyroxene is schillerised and seems to be secondary after the monoclinic variety. Both the

pyroxenes are uralitised along their margins and along the cracks in the interior. Biotite and ilmenite are the other minerals. Apatite and zircon are accessories. Both quartz and feldspars have undulose extinction and the twin lamellæ of the latter are bent. In mineral composition these rocks resemble the charnockites, but they have not the least physical resemblance and show many metamorphic characters both in the field and in the microscopic sections. Ordinary orthogneisses by progressive metamorphism have developed into a hypersthene-bearing gneiss. (See Grove, 1935.)

The sillimanite-biotite gneisses carrying quartz, feldspar—both orthoclase and plagioclase—require no further description.

The dolerite dikes are of the type which occurs in the neighbouring coal field, *i.e.*, they are of Rajmahal lava age. They consist of plagioclase ophitically or sub-ophitically enclosed by the titaniferous pyroxenes, and iron ores. Chlorite has developed at the expense of pyroxene and feldspar and after what appears as cryptocrystalline glass. The presence of this glass distinguishes these from the Newer Dolerites of Singhbhum described by Dunn. (Auden, 1932, p. 97.)

VII. Chemical Characters of the Chief Types

The pure labradorite rock has the composition stated below. This agrees very well with the composition of a labradorite rock described by Kolderup from Bergen.

	1	2
SiO_2	52·20	52·80
Al_2O_3	27·48	28·57
Fe_2O_3	1·33	0·19
FeO	0·56	0·43
MgO	0·14	0·27
CaO	13·00	12·17
Na_2O	3·99	4·82
K_2O	0·49	0·56
TiO_2	Traces	
P_2O_5	0·02	
H_2O	0·55	
H_2O at 110° C.	0·22	
	99·99	99·81

1. Labradorite rock from below the bridge on the Raniganj-Bankura road near the 7th mile-post.

2. Labradorite rock from Bergen, Norway. (Washington, 1917, p. 302).

On calculation, the normative composition of the former indicates a plagioclase with about 65% An., which confirms the composition arrived at from the maximum extinction angle and the refractive index.

The dark anorthosites have the composition stated below :—

	3
SiO_2	48·62
Al_2O_3	27·12
Fe_2O_3	4·30
FeO	2·69
MgO	0·88
CaO	12·53
Na_2O	3·92
K_2O	Traces
TiO_2	Traces
H_2O (+)	0·10
H_2O (−)	0·69
	100·85

3. Anorthosite from the Choupbari, near the road to Mochrakhend. (Chatterjee, 1929, p. 81.)

The oligoclasite from Bardiha has the following composition :—

SiO_2	66·56
Al_2O_3	19·13
Fe_2O_3	·75
FeO	·67
MgO	·11
$Ca O$	5·03
Na_2O	6·08
K_2O	·31
TiO_2	·62
P_2O_5	Traces
H_2O>110° C.	·56
H_2O at 110° C.	·22
	100·09

The normative composition indicates a plagioclase with 30% An.

Composition of the granite from near Mejia :—

SiO_2	77·50
Al_2O_3	9·12
Fe_2O_3	3·29
FeO	0·56
MgO	0·43
CeO	0·44
Na_2O	2·92
K_2O	5·16
TiO_2	Traces
P_2O_5	Traces
MnO	·01
$H_2O > 110°C.$	·34
H_2O at 110°C.	·26
	100·03

The dark-coloured granulitic gabbro or norite has the following composition, which compares favourably with the composition of a norite from Aberdeenshire.

	1	2
SiO_2	48·99	48·58
Al_2O_3	14·69	13·82
Fe_2O_3	*Nil*	1·14
FeO	11·28	12·73
MgO	6·96	5·21
CaO	10·66	9·43
Na_2O	2·92	2·87
K_2O	·78	·76
TiO_2	2·50	3·44
P_2O_5	·31	·64
$H_2O > 110°C.$	·47	·36
H_2O at 110°C.	·16	·05
	100·00	100·18

The greater amount of P_2O_5 in 2 is due to the presence of apatite in the mosaic of basic labradorite (p. 57, Chemical Analysis of Igneous, Rocks, Metamorphic Rocks and Minerals, H. M. Stationery Office, 1931).

Two specimens of the country rocks were analysed, one belonging to the gneiss found near Saltora and the other belonging to the spotted hornblende gneiss intruded by the former. On account of the large amount of hornblende in the latter its analysis does not indicate a definitely sedimentary origin and there is only an excess of quartz and an excess of potash over soda.

	1	2
SiO_2 ...	71·32	68·22
Al_2O_3 ...	13·53	15·09
Fe_2O_3 ...	2·42	4·14
FeO ...	1·80	Trace
MgO ...	·55	1·12
CaO ...	·86	2·78
Na_2O ...	3·07	2·48
K_2O ...	4·67	6·19
TiO_2 ...	·48	...
P_2O_5 ...	·05	...
MnO ...	1·07	...
$H_2O > 110°$ C. ...	·40	·07
H_2O at 110° C....	·07	·18
	100·38	100·87

The first rock is, as has been already noted, a quartzose rock and its specific gravity is 2·52.

VIII. Origin and Interrelation of the Chief Types

A consideration of the field relations of the different rocks occurring within the anorthosite and genetically related to it, together with their microscopic characters and chemical affinities lead to the conclusion that all the rocks ranging in composition from the dark granulitic gabbros to the pegmatite, through the anorthosites, and granodiorites, form a series derived by differentiation from a common parent magma. From the greater prevalence of the gabbroid rocks, and the very small development of the granitoid facies, it may be reasonably concluded that the original magma was gabbroid in composition and was intruded under a great depth of cover leading to slow

crystallisation. The femic constituents began to solidify earlier and together with some palgioclase material gave rise to the dark gabbro bodies varying in size from fine schlieren to huge dikes and lenticular masses. The alternate arrangement of these dark schlieren as thin bands in the anorthosite is such as to force one to recall the convection hypothesis of banding suggested by Grout (Grout, 1918). Field and microscopic evidences conclusively point to their origin by segregation. In the majority of cases they present an intrusive relation to the anorthosite mass and to the country rocks, but this may be due to a later eruptive effort which forced up the material of the basic pole which settled towards the bottom. (Daly, 1914, p. 327.) The sharp contact of the thinner bands and their intrusive mode of occurrence are due to deformative movements in the plastic mass during further intrusive movement.

When the crystallisation of the plagioclase feldspars and the settling of the crystals had advanced to a considerable extent, the magma was subjected to deformative stresses arising out of mountain-building movements and the feldspathic differentiate was displaced. (*Cf*. Daly, 1933, p. 416.) The interstitial liquid already partially expelled by a straining off process, would be squeezed-out along the narrow channels between the closely compacted crystal mushes, where it would be under the influence of great shearing stress at the time of further compression with advancing crystallisation. Thus will originate the numerous pegmatite veins which traverse the anorthosite blocks and ramify in different directions and the sheared granodiorite zones. According to Bowen, anorthosite masses of extreme purity arise in this way by the squeezing-out of the interstitial liquid, and the protoclastic granulation which invariably characterises these rocks was developed as a result of the closer packing of the crystals (Bowen, 1920, p. 160). The granulitic structure of the anorthosite and the gabbros is due to differential movement at the time when the crystallisation was still in progress. The residual liquid may behave like a separate intrusive body, although it is derived from the same parent magma. Looked at in this way the granite dikes occurring in the anorthosite may be regarded as squeezed out residual end portions of the magma owing their position to the phenomenon of auto-intrusion.

DISCUSSION OF THE FIELD AND LABORATORY DATA IN THE LIGHT OF WORK DONE IN OTHER AREAS

According to Bowen (1917), anorthosite rocks formed by the gravitative accumulation of plagioclase feldspars from a gabbroid magma, the residual liquid forming an overlying mass of granite or syenite. This was disputed by Miller (1918 and 1929) according to whom the granite (and the syenite) is a later intrusive and not a differentiate of the parent magma. Grout in 1928 suggested that the phenocrysts will rise in the magma chamber and will form a zone of gabbro grading into anorthosite. This will be again underlain by the residual granitic portion of the magma, which will grade downward into gabbro forming the floor rock. Balk (1930 and 1933) after a careful study of the Adirondack anorthosite, thinks that the granite is derived from the original magma. " The rocks of the syenite series are considered as the frozen mother liquor of the magma." Balk has found numerous shear zones which grade into the massive anorthosite. The rocks of these shear zones represent the residual portions of the mother liquor, which were expelled to form the masses of syenite-granite. This in essence is a modification of Bowen's original hypothesis, but the principles of 'filter pressure' and 'squeezing-out of the mother liquor,' which have been applied by Balk were also advocated by Bowen (1928). In an earlier paper, Bowen had already suggested the origin of anorthosites by crystal settling and the squeezing-out of the residual liquor (Bowen, 1920, p. 160). Buddington (1931) subscribes to the view of common origin of anorthosite, gabbro, and syenite-granite as a result of his study of the north-east Adirondacks. The mafic facies of the anorthosite are due to either 'a greater percentage of crystallisation in place' ......'or through a less efficient squeezing-out of the residual liquid during deformation.'

More recently Grout and Langley (1935), have brought forward evidence to show that in the case of the Duluth gabbro, " the anorthosite formed early and was associated with the granite only after a further differentiation of the gabbro magma to a silicious rest magma." " The late red rock phase of the magma shattered and probably assimilated some anorthosite." (XVI, Int. Geo. Congress Guide-book, 27, 1933, p. 71.)

Balk's ideas fit in nicely with the field facts observed in connection

with the anorthosites of Bengal. The schistose zones consisting of the much crushed and mortarised granodiorites represent the granitic residual liquor. The foliation of these rocks is considered to be of primary origin. Miller (1916) has thoroughly discussed the origin of foliation in the anorthosite and other pre-Cambrian rocks of New York. In the present area under study, the differences in the degree of foliation and granulation in different parts of the anorthosite body and the anorthosite dikes as also in the granulitic gabbros, show that these were due to the movements in the magma before its final consolidation. The rocks no doubt bear the impress of subsequent dynamic metamorphism which further accentuated the original differences in foliation.

Though many of the characters of these rocks, such as granulitisation, undulose extinction, bent twin lamellæ of the feldspars, absence of twinning of much of the feldspars and their general freshness, are primarily due to movements during consolidation, the rocks show evidences of plutonic metamorphism in the secondary origin of garnet and some of the hypersthenes. The hypersthene appears to be primary in the gabbro dike of Bhatuikhend, but the similarities in colour, cleavage, alteration products, and the optical continuity between the hypersthene and the monoclinic pyroxene together with the inclined extinction of the former, suggest strongly that it is secondary in origin in some of the rocks. It should be noted that secondary hypersthene also characterises the older pyroxene-gneisses of the country lying to the north of the anorthosite. Groves has described the development of secondary hypersthene in the orthogneisses associated with the Charnockite series of Uganda (Groves, 1935, pp. 189-191).

It is believed that the anorthosite rock never existed in a liquid state, but the thin veins of anorthosite in older gneiss, and the presence of quartz-bearing varieties show that in certain places it contained a sufficient amount of liquid in between the crystals, which gave the rock its power of flowage. It is for this reason that the dikes contain prophyritic feldspars embedded in a granulosed base. The oligoclasite dikes represent acidic phase of the anorthosite in which the labradorites were further reacted upop by the liquid.

A strikingly noticeable feature of the anorthosite body is the variation in the quantity of the femic constituents present in its different

parts. The increase in the quantity of the femic minerals is accompanied by a greater extent of schillerisation of the feldspars, and the rocks become darker in colour. Even within the masses of the darker varieties there is a good deal of variation in the distribution of the femic minerals, and occasionally the rocks pass into gabbroid types. This is no doubt accounted for by the differences in the rate of the settling of the femic constituents in different parts of the magma, which depended upon the rate of crystallisation and viscosity. The white varieties of the anorthosite are due to a more efficient settling of the femic minerals, at an earlier stage of crystallisation of the feldspars, so that the latter have not been so completely schillerised.

IX. Structure of the Intrusive and its probable Age and Affinities

The nature of the outcrop of the anorthosite body and the parallelism of its strike with the strike of the foliation of the older gneisses which surround it, show that it was intruded as an elongated sheet-like mass between the gneisses. The occurrence of the anorthosite and gabbro dikes away from the main body, however, suggests that it has widened in depth and may have the form of a tilted laccolith. The original extent of the mass towards the east cannot be known, as here it has a faulted boundary with the Gondwanas hidden beneath the Damodar basin. The total area of the visible mass is approximately 100 square miles.

The intrusion is of pre-Cambrian age and is of the same period as the Charnockite series of South India, to which it presents many mineralogical similarities. Suter (1922) believes the anorthositic rocks to be genetically related to the charnockite, but yet anorthosite has not been found anywhere near the charnockites of South India. Later work in the Kalahandi State, where both charnockite and anorthosite occur associated with granitoid gneiss (Walker, 1902, p. 7) might bring out the relationship, if any, between the two rock groups. The majority of the anorthosite bodies belong to the pre-Cambrian, and this may be due to the fact that these rocks require a great depth of cover for their formation by a process of slow cooling and gravitative settling of crystals, and consequently they are found only in those regions which have suffered erosion for an enormous length of time.

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EXPLANATION OF PLATES

Plate I.

Fig. 1—Mode of Occurrence of the dark-coloured Anorthosites.

Fig. 2—Dike of granulitic gabbro or norite showing deformed junction with the white Anorthosite.

Fig. 3—Rock specimens showing the mode of formation of dark schlieren in the white rock by segregation.

Plate II.

Fig. 1—A dikelike included mass of older gneiss in Anorthosite. The junction is irregular.

Fig. 2—Black bands (schlieren) in white Anorthosite.

Fig. 3—Anorthosite dike in older gneiss.

Fig. 4—Thin band of Anorthosite in the gneissic basement.

Plate III.

Figs. 1 & 2—Section of white Anorthosite, showing the unbroken outlines of the anhedral feldspar grains.

Figs. 3 & 4—Shows schillerisation of the large untwinned individuals set in a granulitic base.

Plate IV.

Fig. 1—Shows the stages in marginal granulation of the feldspars.

Fig. 2—Shows the close association of biotite, hornblende and ilmenite. Note the white patch of leucoxene.

Fig. 3—Section of white Anorthosite showing quartz.

Fig. 4—Reaction rims of hypersthene, monoclinic pyroxene and garnet round olivine.

Plate V.

Fig. 1—Shows the formation of garnet by the reaction between pyroxene and feldspars.

Fig. 2—Section of norite.

Fig. 3—Shows the mortarisation of hornblende in hornblende schists derived from gabbros.

Fig. 4—Junction between norite and Anorthosite showing the absence of sharp contact and interpenetration of the minerals of the adjacent fields.

Plate VI.

Fig. 1—Section of granodiorite showing the mortarisation of the constituents and the presence of myrmekite with spherical outlines.

Fig. 2—Section of the grano-anorthosite (hybrid) showing the occurrence of labradorite feldspars in granodiorite.

Fig. 3—Film perthite in Bengal gneiss.

Fig. 4—Hornblende porphyroblast surrounded by granules of hornblende in the hornblende-gneiss of Saltora.

Plate VII.

Fig. 1—Section of granodiorite showing orthoclase, quartz and oligoclase.

Fig. 2—Section of granodiorite showing mortarisation of the constituents and development of myrmekite.

PLATE I.

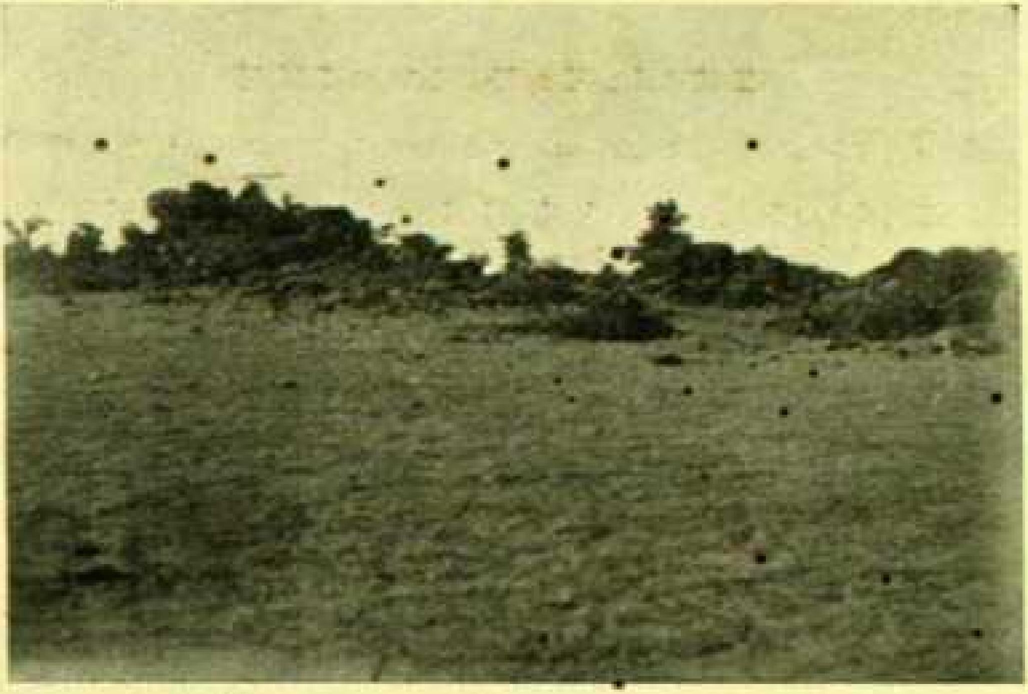

FIG. 1.

FIG. 2.

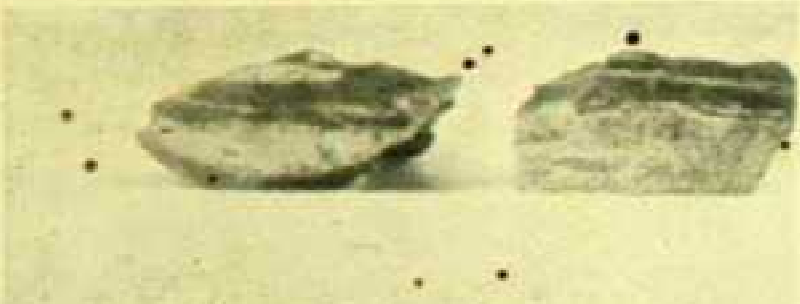

FIG. 3.

PLATE II.

FIG. 1.

FIG. 3

PLATE II.

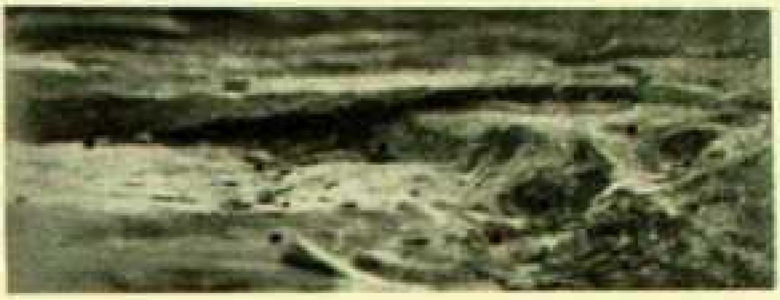

FIG. 2.

FIG. 4.

PLATE III.

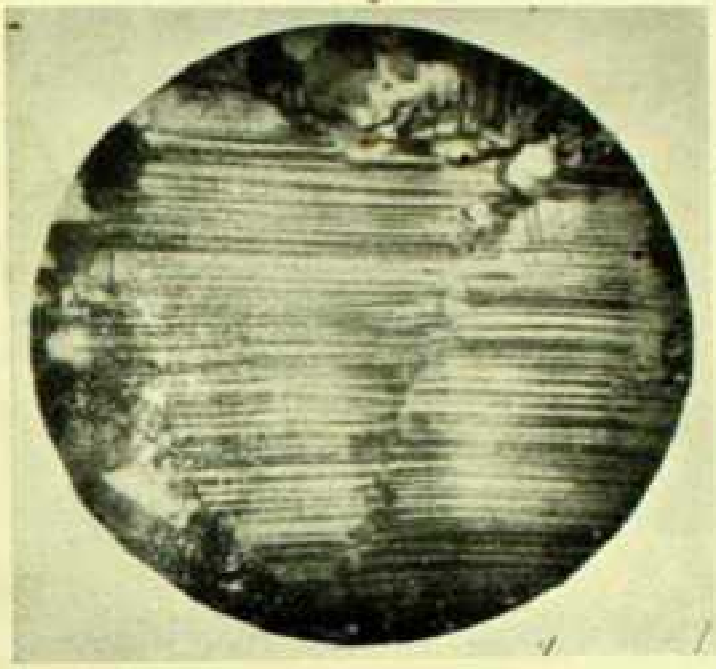

FIG. 1.

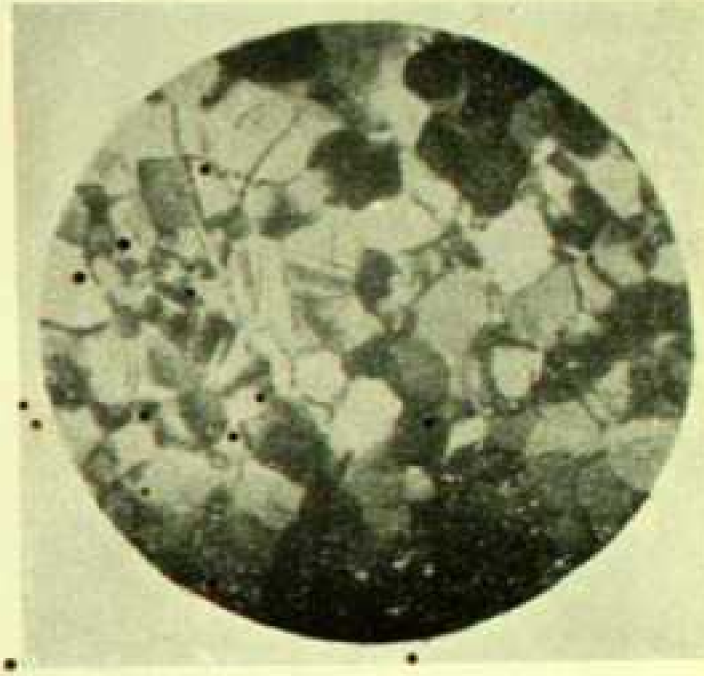

FIG. 2.

FIG. 3.

FIG. 4.

PLATE IV.

FIG. 1.

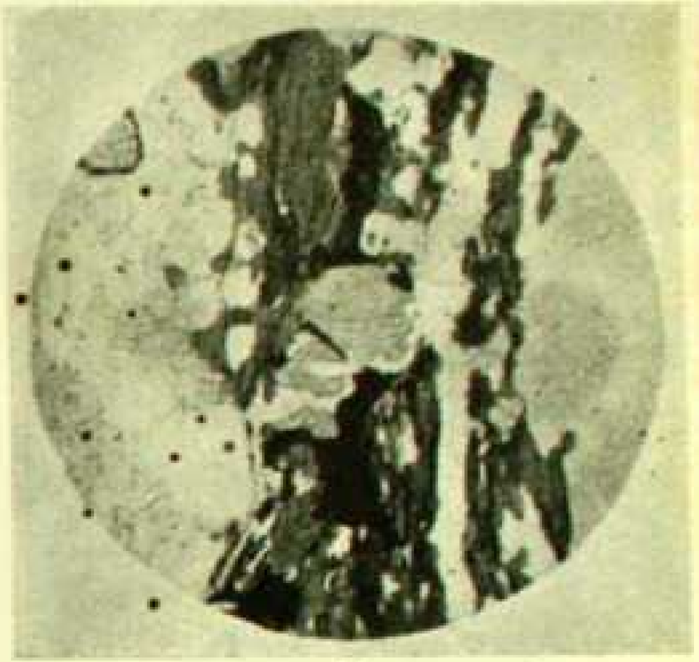

FIG. 2.

FIG. 3.

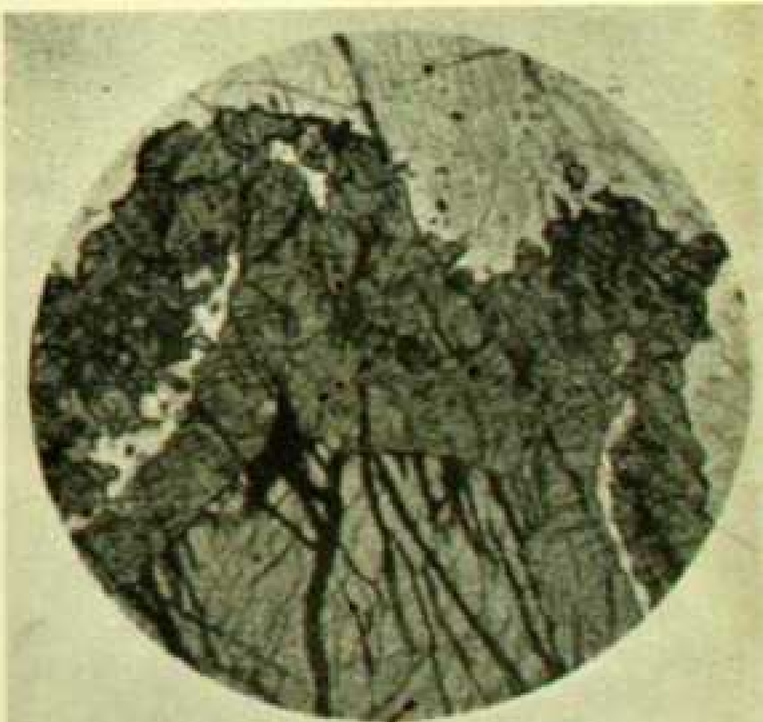

FIG. 4.

PLATE V.

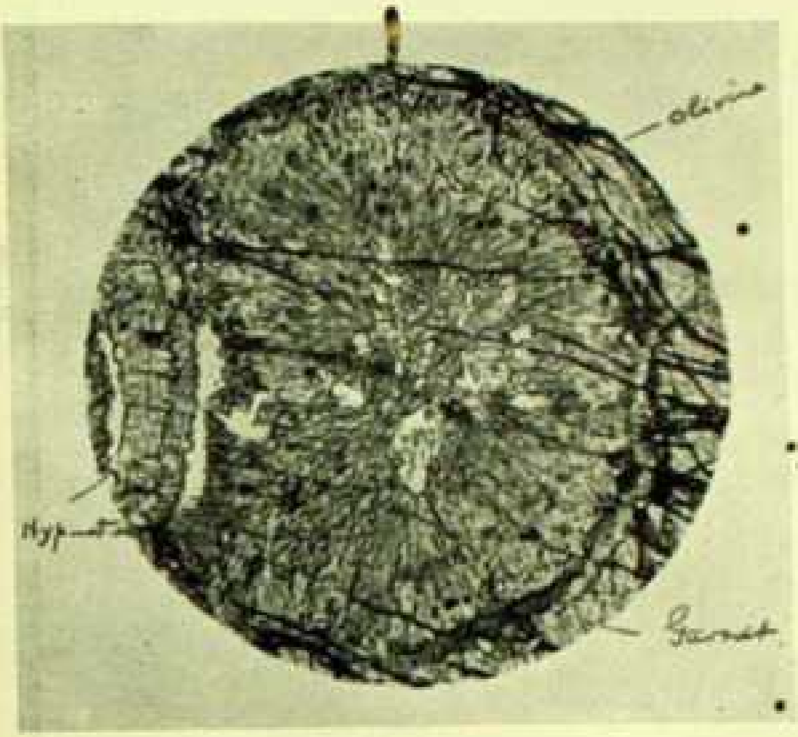

FIG. 1.

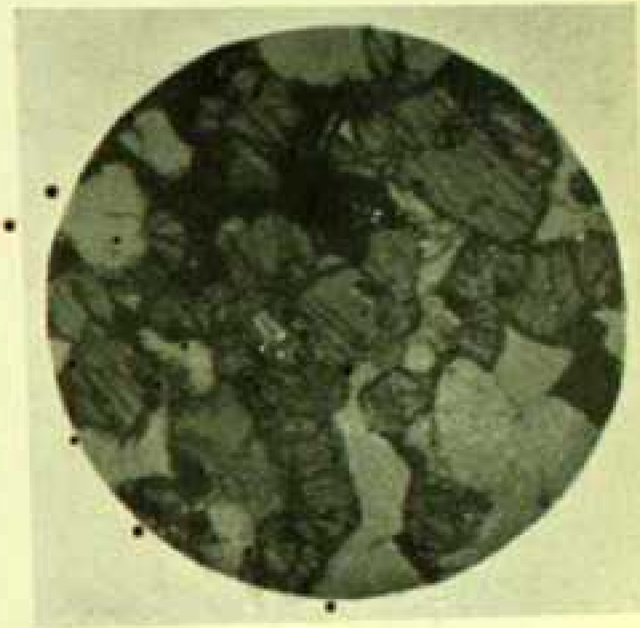

FIG. 2.

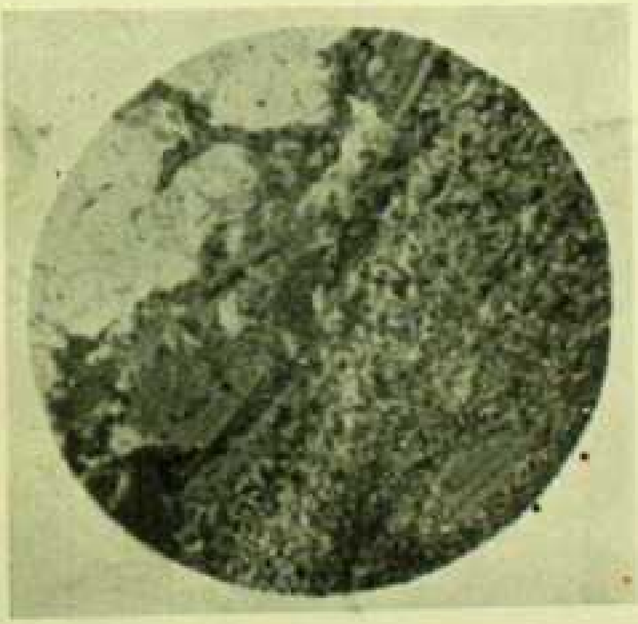

FIG. 3.

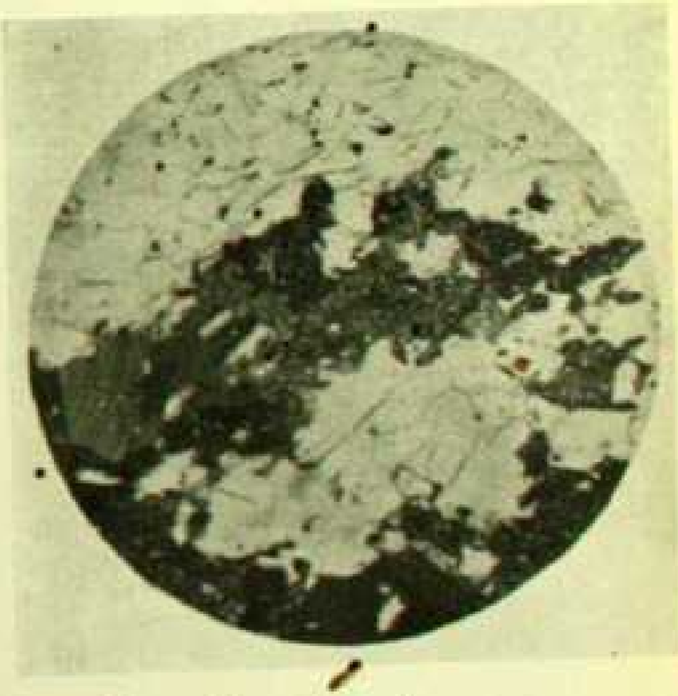

FIG. 4.

PLATE VI.

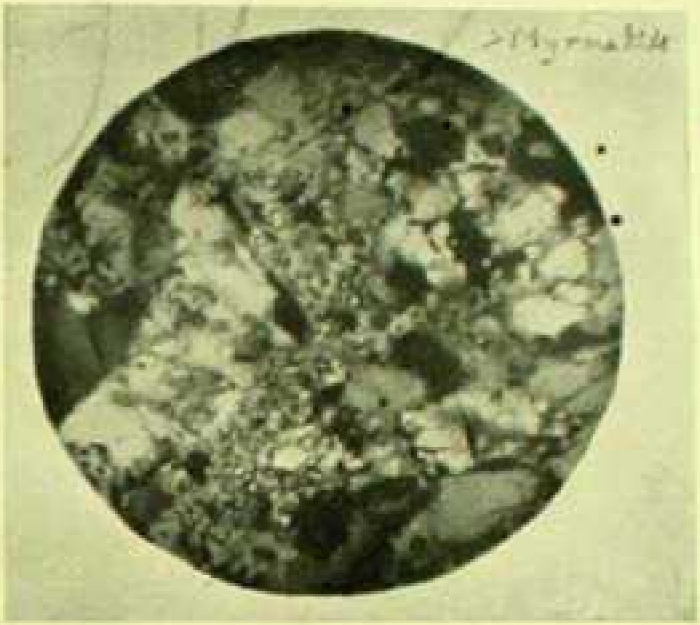

FIG. 1.

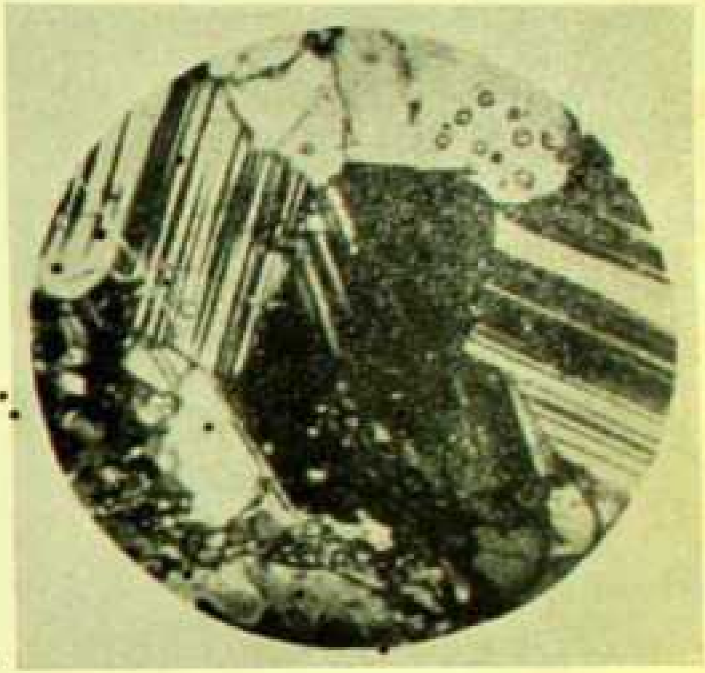

FIG. 2.

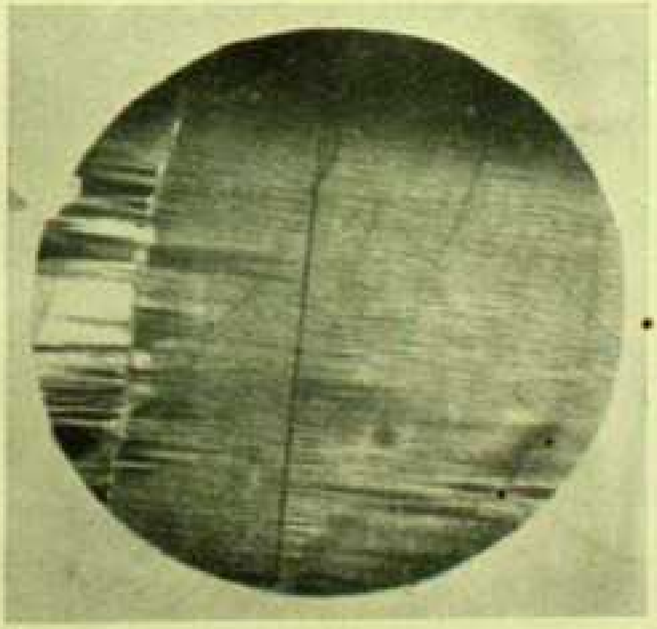

FIG. 3.

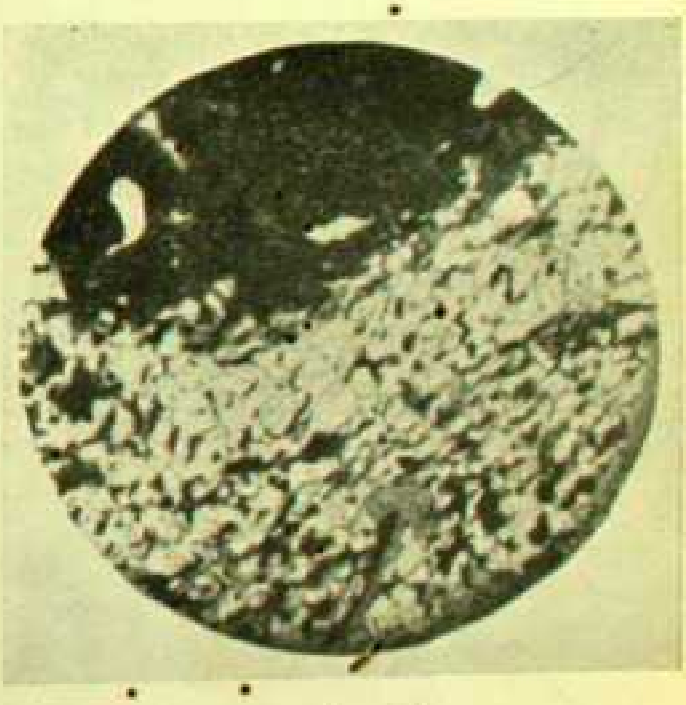

FIG. 4.

Plate VII.

Fig. 1.

Fig. 2.